An analysis on the impact that droughts have had on both the quality and quantity of Cabernet Sauvignon wine grapes in the Stellenbosch region

by

Lennox John Freemantle

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science (Agricultural Economics)

at

Stellenbosch University

Agricultural Economics, Faculty of AgriSciences

Supervisor: Mr Hein Gerwel

December 2020

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: December 2020

Abstract

Droughts are the most globally recognized naturally occurring hazards, that damage agricultural ecosystems and can significantly impact agricultural production. It is therefore important to monitor as well as understand the impact that droughts can have on different agricultural products. This in addition to investigating ways to mitigate the negative impacts caused by droughts. It has been recognized that grapevines are relatively hardy plants and can thrive under moderate water stress as it forces the vine to focus on its reproductive growth. This paper is an analysis of how droughts have influenced the quality and quantity of wine grapes in the Stellenbosch region, with a focus on the Cabernet Sauvignon cultivar in particular. Grape quality is significantly harder to measure compared to yield, as the term grape quality is considered an exceedingly subjective term. That is why this paper aims to investigate specific parameters used to assess grape quality as well as see how these parameters have been influenced by droughts. This is done through an interpretive, inductive mode of inference, in order to grapple with the subjective nature of grape quality. The primary data was collected through a mixed-methods research design, employing a snowball sampling technique through the use of a self-administered questionnaire and semi-structured interviews with different stakeholders in the industry, including viticulturists, winemakers, and farm managers from the different wine routes in the Stellenbosch region. The results of this study indicated that the impact of a drought is site-specific, and that each winery is impacted slightly differently. The findings from this paper show that the implementation and adjustment of certain viticultural practices such as irrigation, cover crops, mulching, and canopy management, can help to mitigate the negative impact of droughts. The findings also revealed that between 2015-2019, nine out of the thirteen of the wineries sampled experienced a decline in the yield of Cabernet Sauvignon grapes. It was however made clear that vines planted on rich deep soils which contain a percentage of clay, tended to experience a smaller decline in yield and in some cases even led to an increase in yield. During the same period, it was also noted that grape quality in certain instances increased due to smaller berries with better colouring, as well as an increase in the skin to pulp ratio. This led to more concentrated flavours, however in some cases the water stress resulted in a substantial increase in leaf roll symptoms in vines, as well as other problematic quality parameters. These included the increase in the fructose-glucose ratio, which impacted the winemaking process. It is therefore inconclusive whether the decline in Cabernet Sauvignon grape yield caused by droughts can be counterbalanced by an increase in grape quality during the same period in the Stellenbosch region.

Opsomming

Droogte is wêreldwyd die mees herkenbare natuurlike gebeurtenis wat die landbou ekosisteem beskadig en kan 'n beduidende impak hê op landbouproduksie. Dit is dus belangrik om dit te monitor, sowel as om die impak wat droogte op verskillende landbouprodukte kan hê, te verstaan. Daarbenewens is dit nodig om metodes te ondersoek wat die negatiewe invloed van droogte kan verminder. Dit is bekend dat wingerdstokke redelike sterk plante is en kan floreer onder matige waterstres, omdat dit die wingerdstok forseer om te fokus op voorplantingsgroei. Hierdie studie is 'n analise van hoe droogte die kwaliteit en kwantiteit van wyndruiwe in die Stellenbosch-streek beïnvloed, met klem op die Cabernet Sauvignon kultivar. Dit is moeiliker om druiwekwaliteit te meet in vergelyking met opbrengs, omdat druiwekwaliteit ‘n uiters subjektief term is. Hierdie studie stel dus ondersoek in na spesifieke parameters wat gebruik word om die kwaliteit van druiwe te meet, sowel as die invloed van droogte hierop. Dit word gedoen met behulp van ‘n interpreterende, induktiewe metode van gevolgtrekking, deur die subjektiewe aard van druiwekwaliteit aan te pak. Die primêre data is versamel met behulp van ‘n kombinasie van navorsingsontwerpmetodes, deur die aanwending van 'n sneeubal steekproef tegniek. Dit is gedoen deur die gebruik van ‘n self-geadministreerde vraelys en onderhoude met verskillende rolspelers in die industrie, insluitend wynbouers, wynmakers en plaasbestuurders van die verskillende wynroetes in die Stellenbosch streek. Die resultate van hierdie studie dui aan dat die impak van droogte, area-spesifiek is en dat elke wynkelder tot ‘n mate verskillend beïnvloed word. Die bevinding van hierdie projek dui aan dat die implementering en aanpassing van sekere wynboumetodes, soos byvoorbeeld besproeing, dekgewasse, deklae, lower bestuur, en verdere bestuursmetodes, kan help om die negatiewe invloed van droogte te verminder. Die studie bevind ook dat nege uit dertien van die wynkelders se wyn wat ondersoek is, 'n afname in die opbrengs van Cabernet Sauvignon druiwe gehad het in die periode 2015 - 2019. Dit was duidelik dat wingerdstokke wat in ryk, diep ground met 'n persentasie klei geplant is, geneig was om ‘n kleiner afname in opbrengs te hê. In sommige gevalle was daar selfs ‘n verhoging in opbrengs. Terselfdertyd is daar ook opgelet dat die kwaliteit van druiwe in sommige gevalle verbeter het, met kleiner korrels en beter kleur, sowel as 'n verbetering in die dop en pulp verhouding. Dit het gelei to 'n beter smaakkonsentrasie, maar in sommige gevalle het vogspanning gelei tot 'n aansienlike toename in siektesimptome van die wingerdstokke, sowel as ander problematiese kwaliteitsparametes. Dit sluit in, 'n toename in die fruktose - glukose verhouding, wat 'n invloed op die wynmaakproses gehad het. Dit is dus onduidelik of die afname van Cabernet Sauvignon druifopbrengs, veroorsaak deur droogte, uitgebalanseer kan word deur 'n verbetering van druiwekwaliteit tydens droogtes in die Stellenbosch streek.

Acknowledgements

This thesis would not have been possible without my the continues support and guidance from my friends and family, to whom I owe a great debt of gratitude:

- First I would like to thank my amazing parents Eric and Tamsin, for the endless encouragement, financial support as well as your continued love. A special mention to my mom for taking the time to read through my thesis and provide guidance with regards to my grammar and sentence structure.
- Second to my incredible gran Joyce, for the daily phone calls to lift my spirts and keep me grounded and for that I will be forever grateful.
- To my incredible girlfriend Kristan, thank you first always being there for me and keeping me sane as well as always going above and beyond to help support and reassure me during the difficult times.
- My supervisor, Mr Hein Gerwel, for his valuable insight into my topic as well as your guidance, support and patience through this journey.
- Dr Philip Myburgh, for all his valuable information and data on this topic.
- My colleagues from the department, with a special mention to Kyle and Brad Boast, for their support and advice throughout my six years at Stellenbosch university.

Table of Contents

List of Figures

List of Tables

Chapter One: Introduction

1.1 Background and Rationale

The Western Cape has faced a number of severe droughts in recorded history. The most recent one began in 2015 and three years later the Western Cape started preparing for the so-called “day zero”. Day zero is a term used to describe the day that average dam levels reach 13.5% and the water coming out of taps is turned off (Fourie, 2018). Droughts often lead to water restrictions in an attempt to try and reduce water consumption. The Western Cape has had a bad history when it comes to droughts, with the last two major droughts having occurred in 2003 and 2015 (Midgley et al, 2005). The drought that started in 2015 had a significant impact on agriculture, livelihoods, and communities in the Western Cape, which directly impacted the South African economy. This drought caused an estimated economic loss of R5.9 billion to the agriculture sector in the Western Cape alone. It also resulted in 30 000 job losses and a significant decline in agricultural exports of between 13-20%. This is an estimated economic loss, mainly attributable to the reduced farming outputs and additional income losses as export volumes declined. A large number of hectares of productive fruit trees and vineyards have been removed ahead of the normal replanting schedule, due to the lack of available water as well as to prevent disease and pests from spreading (WWF. 2018).

The agricultural sector in the Western Cape has been severely affected by droughts as most farms experienced a reduction in yield and quality of produce; wine grapes however are slightly different. A drought normally causes a decrease in yield, although the quality of the grapes in many cases improves. Smaller grapes are produced in dry and hot conditions and have more intense colour and flavour with higher sugar content (Chaves et al, 2010). According to the SAWIS publication the wine industry directly and indirectly employs roughly 300 000 people, including farm owners, farm labourers as well as many other individuals who work along the wine value chain. 320 million litres of wine was exported from South Africa in 2019, which is 24% less than the previous year. This is linked to the reduction in output, due to the compounding effect of the drought. The study also concluded that the wine industry in the Western Cape is responsible for contributing R36.1 billion to gross domestic product (GDP), which is approximately 1.3% of the total GDP of South Africa. The wine industry is a major role player in the Western Capes agricultural sector. This is why it is an important sector, especially in the context of the Western Cape. The wine industry’s profitability however is a serious problem, as there is a worldwide oversupply of wine. Only producers that can sustain very high yields can consistently break even (SAWIS, 2015).

South Africa is the eight biggest wine producer and ninth-largest wine exporter globally, exporting 320 million litres a year, in addition to the 400 million litres sold locally. This makes South Africa responsible for 3.3% of global production, however, with the predicted long-term drying trends that are expected to take place in the Western Cape, there are many challenges that the wine industry will face (Cholette, et al. 2005; SAWIS, 2020).

Quantity and quality are two important factors to consider when it comes to profit. Both of these factors will influence revenue and expenses. Total revenue is equal to quantity multiplied by price, so if quantity decreases but the price stays the same, total revenue will decrease. Price can, however, be influenced by quality. The

focus of this thesis is on how droughts affect the grape quantity and grape quality, to see if these changes caused by the drought will counterbalance each other. This thesis will focus on the Cabernet Sauvignon variety, as it is one of the standout cultivars within Stellenbosch. It is also the most distributed wine grape cultivar of both red and white wine grape cultivars within Stellenbosch, with 19.67% of the total number of hectares planted being Cabernet Sauvignon (SAWIS, 2018).

1.2 Research Question, Aims, and Objectives

This study focuses on the Stellenbosch region, and will look at the effect of droughts on the decline in the quantity of grape production, and if this is counterbalanced by the increasing quality of grape production in terms of profit. Questions that will be asked include:

- How do drought periods impact Cabernet Sauvignon grape yields in the Stellenbosch region?
- How do drought periods impact Cabernet sauvignon grape quality as well as the wine quality?
- Will the drought cause the quantity of the grapes to decrease but improve the quality?
- How will the impact of droughts be felt by the wineries in the different sub-routes in Stellenbosch?
- Will wineries continue to grow cabernet sauvignon grapes if droughts become more common?
- How will drought conditions influence the price of grapes?
- Do droughts cause farmers to plant more resistant grape cultivars?
- What viticultural practices would be implemented during drought periods to optimise quality as well as yield?
- How does the market response to quality and what is the real value of Cabernet Sauvignon wine grapes from the Stellenbosch region during drought periods?

The purpose of this thesis is to investigate the impact droughts have on both quality and yield of wine grapes, in particular Cabernet Sauvignon grapes. The term quality is considered as being a very subjective term and therefore this thesis aims to investigate which parameters grape quality can be measured by, as well as to see if droughts positively or negatively affect these parameters. Once these parameters have been established, the study will then investigate how these parameters can be optimised during drought periods, to give wineries a guide that they could utilise during similar periods in the future.

1.3 Literature Review

The literature review will be broken up into two main parts which can further be subdivided into subsections. Part one begins by defining *terroir*, in particular climatic factors that influence wine grape production. It then unpacks climate change and analyses how certain scenarios can impact wine grape production. This is followed by the impact of irrigation on wine grape production under certain conditions. The second part of this literature review begins by analysing certain aspects of Cabernet sauvignon as a cultivar, and then it will look at how

the quality of grapes, as well as of wine is measured, focusing on the Cabernet Sauvignon cultivar. It will then investigate how different viticultural practices influence grape and wine quality and finally it will discuss how drought and water availability impact the yield as well as the quality of grapes, in addition to wine production.

1.4 Methodology

This thesis uses a mixed methods approach, as it allows the integration of both the qualitative and quantitative data, in order to interpret the data as a collective rather than in isolation. For this reason, it is the preferred method for this thesis. Self-administrative questionnaires and semi-structured interviews were the tools used to collect data for this thesis. The respondents were selected using a snowball approach, as it was difficult to get respondents to participate; the questionnaire was relatively lengthy and was a time-consuming process to complete. The primary data was collected from viticulturists, winemakers or harvest interns on certain wineries, as well as from key stakeholders in companies within the wine industry. The self-administrated questionnaires allowed the respondent to answer the questions in their own time, without being prompted for answers by the interviewer. Certain follow up questions were however emailed and were used to get clarity on specific questions. The semi-structured interviews took place at the wineries, and the interviewer was present. This allowed certain follow up question to be asked, in order to get the respondent to elaborate on certain answers. Some of the questions used a five-point Likert Scale as a way to quantify quality. This has been established as one of the best ways to measure people's opinions and perceptions and is an easy scale to construct to collect qualitative data (Zikmund et al, 2010). These questionnaires helped collect data from these wineries on a micro-scale and once analysed, case studies were created to show how the drought has affected each farm. In essence they were used to see if droughts will cause the decline in the quantity of grape production to be counterbalanced by the increasing quality of grape production.

1.5 Data Management and Analysis

Once the respondents agreed to take part in this study, they had the option to either answer the questionnaire via email or answer the questions through an in-person semi-structured interview. The self-administrated questionnaire was the simpler of the two methods, as the questionnaire was emailed to the respondents and they could fill it in at their own pace and send it back completed; this meant that the data was already typed. The in-person semi structured interviews took place at the various wineries where the respondents worked. Certain of the respondents agreed to have their answers recorded whereas others did not. Nevertheless, written notes were taken by the author, to highlight certain reactions and responses. After the interview was conducted the author transcribed the answers given by each respondent into an extended document. The answers from each respondent were categorised according to the sub-route in which the winery is located. Once the data from the two separate methods was transcribed and categorised into the different sub-routes, the data was analysed. Once the data was transcribed, it was saved on a password- protected drive, as well as being backed up on an external hard drive in case something happened to the original copy. The data in the extended document was colour coded into themes and phrases. Each paragraph was broken down into smaller components which were then typed into the margin, making it easier to locate and interpret certain themes and

phrase which occurred in the data. Colour coding the data was also used to make it easier to locate certain themes to write up the findings.

1.6 Ethical Considerations

Due to the fact that data collected included personal opinions, as well as information that could impact the reputation of the winery as well as respondents' reputations, ethical clearance was needed to get both the wineries and the respondents' consent to use their information in the study, and to find out if they had any requirements before answering the questions. The participants that took the time to fill in the questionnaires had the right to know who would have access to their data and what would be done with their information. This project falls into the category of low risk as it is focusing on personal opinions around the quality and quality of grape production during drought periods. However, participants had the option to remain anonymous as well as refuse to answer certain questions. To reduce the anticipated inconvenience to the participants, the surveys were limited to an hour per person. In order to reduce the inconvenience, each participant was given a consent letter to sign before they could take part in this study. The consent form briefly explained the outline of the project, as well as how and why this thesis is being conducted in order for the participant to be fully informed before accepting to take part in the study.

1.7 Strengths and Limitations

One of the strengths of this thesis is that the topic is very relevant in today's ever-changing climatic environment. Many people are debating the effects droughts have on the South African wine industry and the impact they have on the quality and yield of wine grape production. Another strength of this thesis is that it tackles and unpacks key parameters around the so-called "taboo concept" of wine grape quality. The concept of wine grape quality is often avoided due to its level of subjectiveness, however this thesis uses an inductive hermeneutic approach to analyse this concept and discuss how the drought impacts wine grape quality on a farm level. The main limitation of this thesis is the lack of available farm-level data and therefore primary data had to be collected. Primary data was collected by approaching farm managers, viticulturists, winemakers, and harvest interns, however these individuals are very busy during the harvest period from January till April and are almost impossible to get hold of at this time. The number of respondents was also restricted by COVID-19 as face to face interviews was not possible during a large part of 2020. Due to these reasons only sixteen respondents agreed to take part in the study. Unfortunately, none of wine farms where the respondents worked bought or sold Cabernet Sauvignon grapes and therefore their response regarding the relationship between quality and price was limited. It also needs to be noted that all the wine farms used in this thesis produced their own Cabernet Sauvignon grapes to produce their wine. Respondent one to thirteen worked at the various wine farms in various capacities. The last three respondents worked at companies within the wine industry. Many of the respondents were also not willing to share specific farm information and tended to hold back on important information or did not elaborate fully on certain questions. This limitation was minimized by giving the respondents context to the study in addition to stating in the consent form that if the estate is willing to be part of the study, they can contribute to a research gap in the agricultural industry. Another limitation that this

study faced was the issue of biased responses to the questionnaire. These will occur as respondents will try not to talk badly about their products, which they are passionate about, and there is the chance that some of the responses tend to be positively biased towards how the drought has impacted quality. A further limitation that arose during this thesis is the fact that the term grape quality is a subject one and there is no exact way to measure the quality of wine grapes. Consequently, certain proxy measures were used to try and measure the quality of the grapes as well as to illustrate how droughts impact this concept.

Chapter Two: Literature Review

2.1 Introduction

The objective of this literature review is to unpack how droughts affect the quantity and quality of wine grape production, as well as the wine produced from these grapes; the focus is specifically on Cabernet Sauvignon grapes produced in the Stellenbosch region in the Western Cape. Conclusions will be drawn by studying literature from around the world and narrowing it down to a South African context, and more specifically the Stellenbosch region. The grape variety most commonly used to make wine is called Vitis vinifera. Most of the grapes produced in the Stellenbosch region are grown to produce quality wines. This is a key aspect that needs to be monitored, as it is virtually impossible to produce high-quality wine with low-quality grapes. An American viticulturist named Robert Mondavi once said: "You can make bad wine with great grapes, but you can't make great wine with bad grapes."

The literature review will be broken up into two main parts which can further be subdivided into subsections. Part one begins by defining terroir, in particular climatic factors that influence wine grape production. It then unpacks climate change and analyses how certain scenarios can impact wine grape production. This is followed by examining the impact of irrigation on wine grape production, under certain conditions. The second part of this literature review starts by analysing certain aspects of Cabernet Sauvignon as a cultivar; secondly, it will look at how the quality of grapes, as well as wine (in particular the Cabernet Sauvignon cultivar) is measured; thirdly it will investigate how different viticulture practices influence grape and wine quality, and finally, it will discuss how drought and water availability impact the yield as well as the quality of grapes in addition to wine production.

2.2 The classification of terroir

The quality of grapes is affected by numerous factors such as terroir, cultivar, and vineyard management (Morris, 1998). Each one of these factors can be broken down into smaller components and these components can often be linked to one another. The term terroir originates from the French word '*Terre'* which means land and its characteristics (Cross *et al*, 2011). Terroir, in essence refers to specific site attributes such as climate, slope, aspect, elevation, and soil type.

Grape producers and wine estates use terroir as a tool to identify the geographical origin of the grapes used to produce the wines. The characteristics of wine can also be linked to the terroir and can also influence the price of the wine. For example, burgundy is known to produce some of the most expensive wines in the world such as Romanée-Conti Grand Cru or Domaine Leroy Musigny Grand Cru, which are both made from Pinot Noir grapes which is what burgundy is known for (Dangremond, 2019). The unique characteristics of both New Zealand Sauvignon Blanc and Stellenbosch Cabernet Sauvignon, identifiable by a sommelier, are two more examples of how characteristics of wine can also be linked to terroir (Manske & Cordua, 2005).

Climate can be broken down further into four main components: temperature, humidity, precipitation, and wind. All these factors impact grape production, which directly influences the end product (Cross *et al*, 2011).

The climate of a certain area is one of the first indications of whether grape production is firstly possible, and secondly how well suited the vines will be to the location and is the ultimate driver of economic sustainability; for example, high levels of humidity can increase the probability of diseases and pests within a block of vines. A further example is strong winds having the ability to physically damage grapevines as well as the grapes (Myburgh, 2018). Gregory Jones, a research climatologist specializing in the climatology of viticulture and reputed to understand climate's influence in the production of wine grapes and wine production, says that one must consider four important aspects. Firstly, the climate conditions needed for optimum grape quality and production characteristics, secondly, how the climate influences the suitability for different wine grape cultivars, thirdly, the climate's variability in wine-producing regions, and finally how the climate change influences the grape quality and production characteristics in terms of structure, style, and suitability (Jones, 2010).

In 1918 a German botanist-climatologist named Wladimir Köppen published an empirical climate classification system that allowed people to group different climatic zones on a map; this helped viticulturists to determine which areas were suitable for wine grape production (Bois *et al*, 2016). In South Africa there are many different climatic zones as seen in figure 2.1, however, not all climatic zones are appropriate for the production of wine grapes.

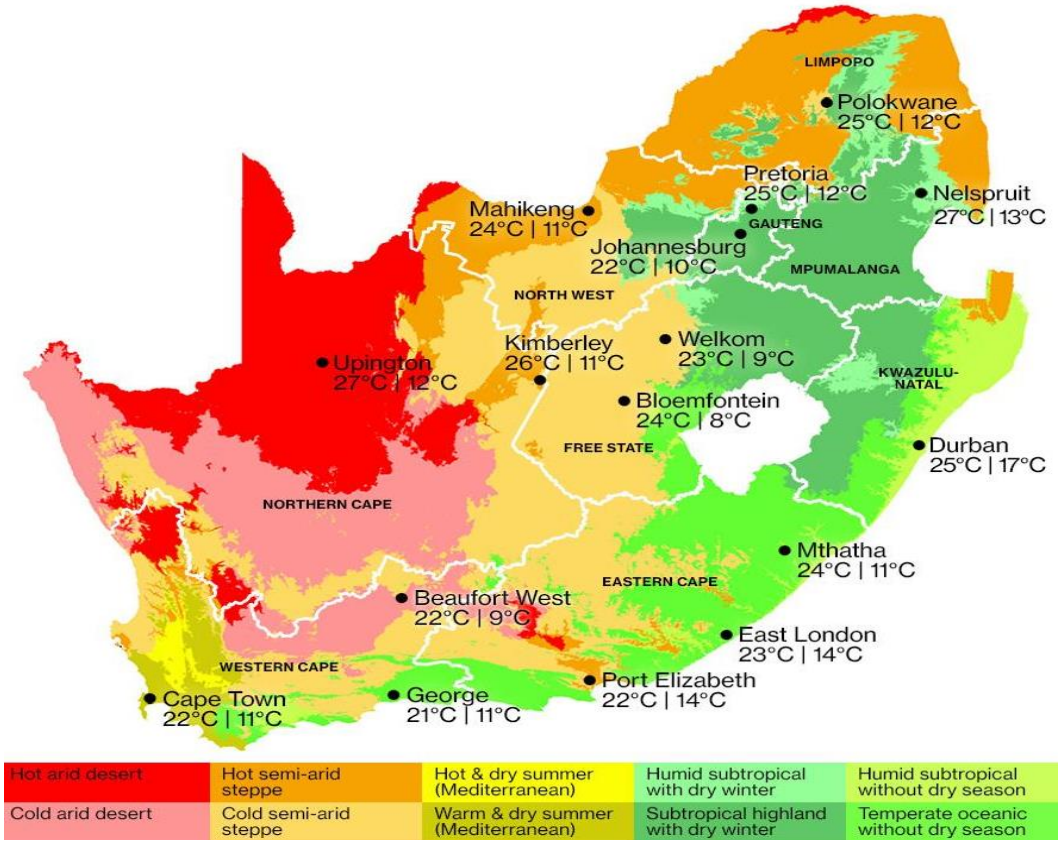


Figure 2.1: climate types for South Africa according to the Koppen-Geiger classification Sourced from Maps-Southafrica.com, 2020

In South Africa, wine grapes are grown in two main climatic areas. The majority of wine grapes are grown in the Western Cape, which is regarded as having a Mediterranean climate. This is the first of the two climatic zones suited for wine grape production and is the focus for this study. The Western Cape typically has warm, dry summers and mild, moist winters. Wine grape production that occurs near to the coast faces summer temperature that rises from a low of 15º C to a moderate 27º C. Inland wine grape production areas such as Stellenbosch, temperatures are approximately 3-5º C higher (Myburgh, 2018).

2.2.1 Temperature

Historically there are numerous ways to measure temperature, to find out what the optimum range would be for the different wine grape cultivars. These are the Growing Degree-Days index (GDD), and the long term mean February temperature (MFT) (Gladstones, 1992; Tonietto & Carbonneau 2004; Jones, 2010). In 1944 Dr. Winkler, with the help of his colleague, Dr. Amerine, created what is today known as the Winkler index. This has been used to show the relationship between climatic zones and potential wine quality, focusing on the California area. Over the years The Winkler index has been applied to different countries, such as South Africa. The main drawback of the Winkler index is that it only focuses on temperature and does not consider any of the other climatic factors.

Table 2.1: Wine quality potential classification according to the GDD

Region	GDD	Wine potential quality According to Le roux 1974	Wine potential quality According to De Villiers et al 1996
1 (cold)	<1390	good quality white table wine and light red wines	High-quality white table wine
2 (cool)	1391 - 1670	Good quality red and white table wine	High-quality white and red table wine
3 (moderate)	1671 - 1940	Good quality red wines and port	High-quality red table wine
4 (warm)	1941 - 2220	Dessert wine, sherry and standard wine	Low acid and high PH
5 (very warm)	>2220	Dessert wine and Brandy	Low acid and high PH

Source adjusted from De Villiers *et al*, 1996; Le roux. 1974

The table above uses the GDD to divide regions into five temperature-related categories, ranging from cold to very warm, and links each region to the type of wine that could be expected in terms of wine quality potential. The table shows that the cold/cooler regions can produce good quality white wines as well as lighter style red wines such as Pinot Noir. The warm and very warm regions are better suited for the sweeter dessert wines and sherries.

Table 2.2: Climate regions in the Western Cape and their suitable cultivars

Regions	GDD	MFT	Suitable cultivars	Locations in the Western Cape
Region I	<1390	<19.8	Pinot Noir, Riesling, Chardonnay, Gewürztraminer and Pinot Grigio	Piketberg and Lamberts bay
Region II	1391 - 1670	19.9 - 21.3	Chardonnay, merlot, Semillon, Syrah and Sauvignon Blanc	Elgin, Elim, and Vredenburg
Region III	1671 - 1940	21.4 - 22.8	Grenache, Barbera, Tempranillo, and Cabernet Sauvignon,	Stellenbosch, Franschoek and Philadelphia
Region IV	1941 - 2220	22.9 - 24.3	Syrah, carignan, Cinsault, Mourvedre and Tempranillo	Paarl, Malmesbury, and spice route
Region V	>2220	>24.3	Primitivo, Fiano, and Palomino	Porterville, Wellington, and Klawer

Source Adjusted from Easton, 2010.

Table 2.2 can be used as a guide to indicate which cultivars are most likely to grow successfully in the different regions found in the Western Cape, and links specific locations to specific cultivars. The table however, needs to be updated as new technology, new cultivars, and climate change can impact these results. A location such as Piketberg would be classified as a region one, as its GDD is below 1390 and therefore the best-suited cultivars would be Riesling, Chardonnay, Gewürztraminer and Pinot Grigio in terms of white cultivars, and Pinot Noir in terms of red cultivars.

Wine grapes grow best in areas with cold and wet winters, warm springs, and warm to hot summers - with little precipitation in summer - this allows the necessary phenological growth stages to take place. Each grape cultivar is however unique, and no single cultivar suites all climates so it is important to match cultivars with the correct terroir to get the best results in terms of quality and yield (Jones & Davis, 2000). Temperature has the largest influence on the overall growth and productivity of wine grapes, followed by precipitation. The ideal temperature range for most wine grape cultivars is between 12-22°C, and this includes many wine grape growing areas such as Burgundy and Bordeaux in France, California in American, New South Wales in Australia and the Western Cape in South Africa (Jones, 2010).

The first phenological growth stage after dormancy is budburst. This stage starts to occur when the mean daily temperature exceeds 10°C for at least seven consecutive days, which normally occurs in early spring (Jones & Davis, 2000). The temperature and rainfall from dormancy until harvesting will impact the quality of the grapes. Higher temperatures will cause grapes to ripen earlier in the season and cause the grapes to have a higher sugar concentration, which has the potential to cause the wine made from these grapes to have a higher alcohol content. Temperature affects the aromas of the wine made from the grapes. White wine cultivars growing in cool climate areas, such as Elgin, tend to be fresher and more acidic with fragrant aromas. In contrast, white wine cultivars in warmer climates, such as the Swartland, will have higher sugar concentration, making them sweeter. Consequently, increased sugar content causes the wine to have higher alcohol content. Thus, cooler climates are often preferred for white wine cultivars, in addition to the lighter styled red wine cultivars such as Pinot Noir (Goldammer, 2018).

Most red wine cultivars prefer the warmer temperatures. The higher temperatures cause the colour and flavours to be enhanced, lowers the acid levels, and increases sugar concentration (Coombe, 1986). Extreme temperatures, above 35°C or below 15°C, between budburst and harvest, can lead to the grapes not developing properly. Extreme temperatures could reduce the quality of the grapes, thus the ideal temperature range for high-quality grapes is 18°C to 30°C. White cultivars prefer slightly lower temperatures than red cultivars (Coombe, 1986).

2.2.2 Precipitation

The second most important climatic factor for wine grape production is precipitation. Just like any other plant, a vine will die without enough water, be it from rainfall or irrigation. In Ted Goldammer's Grape Grower's Handbook: A Guide To Viticulture for Wine Production, the recommended minimum level of rainfall/irrigation is 20 inches (500 mm) per year; however, if the area has a very hot growing season, it will have high evapotranspiration rates and the vines will require more water. This can be overcome by regular irrigation, if available and allowed (Goldammer, 2018; Jones, 2015).

There have been numerous studies done on the relationship between water availability and wine grape yields over the years. In 1984 Jan Louis van Zyl completed his Ph.D. which investigated the interrelationship between grapevine and soil water availability. This research showed that the lack of soil water and water stress, in general, will eventually cause a decrease in grape yield. This is due to the water stress causing a decrease in the number of flowers per inflorescence, in addition to restricting cell division so both the bunches and the berry size are reduced. Once the water stress gets too severe, it will cause berries to fall off the vine, as it needs to focus its energy on survival rather than reproductive growth (Van Zyl, 1984). The opposite is also true - an increasing water availability for vines tends to cause an increase in yield in both bunch size and berry size. A study conducted in Napa Valley, California, indicated that by doubling the water availability, a vine will increase it yield by roughly 30-40% (Chalmers, 2012).

In Phillip Myburgh's handbook for irrigation of wine grapes in South Africa, he investigated the effects of July and August rainfall on the yield of dryland Cabernet Sauvignon near Philadelphia, between 2014 and 2018. He then plotted the results graphically and they can be seen in the figure below.

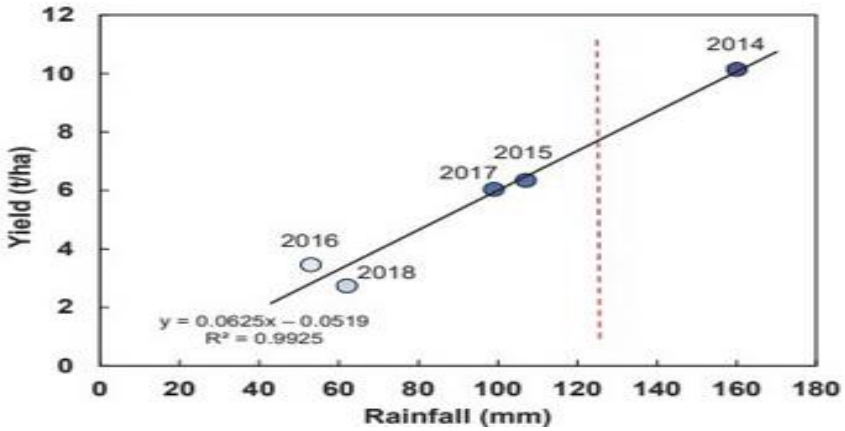


Figure 2.2: The impact that July and August rainfall had on the yield of dryland Cabernet Sauvignon near Philadelphia, sourced from Myburgh, 2018

In Figure 2.2 it is clear to see that there is a positive relationship between rainfall and yield. During the drier years, the yield was significantly lower than years with excessive rainfall; the red dotted line indicates that the 71 year mean rainfall for the area which shows that between 2015 and 2018 there was less rainfall than the average. The high R-squared (coefficient of determination) indicates that there is a strong positive relationship between rainfall and Cabernet Sauvignon yield. This indicates that rainfall is an essential climatic variable when it comes to grape yield, especially in dryland vineyards such as this one near Philadelphia (Myburgh, 2018).

The timing of water availability is also vital in wine grape production. During certain periods of the year the vine needs less water than in others. To understand at what growth stages the vine needs more or less water, it is important to firstly understand the growth cycle, which includes five different stages. The growth stages are as follows: from budburst to flowering, flowering to fruit-set, fruit-set to veraison, veraison to harvest, and post-harvest. In the southern hemisphere in particular, the Western Cape of South Africa, bud burst occurs in late August to early September and continues through to the end of September for most wine grape varieties (Chalmers, 2012). Flowering and berry set occur in early to mid-November. Between bud burst and flowering the vine focuses on vegetative growth during which the leaf canopy is established. After flowering, fruit set occurs, and berries begin to form and grow until around veraison in January, where sugars accumulate in the berries, and acid begins to decrease. Berries will start to reach maturity from around February till the end of March, depending on the cultivar. Once the berries are ripe, they will be harvested between February and March (this is cultivar dependent), after which leaf fall occurs around mid-May, when the vine goes back into a dormant state (Chalmers, 2012).

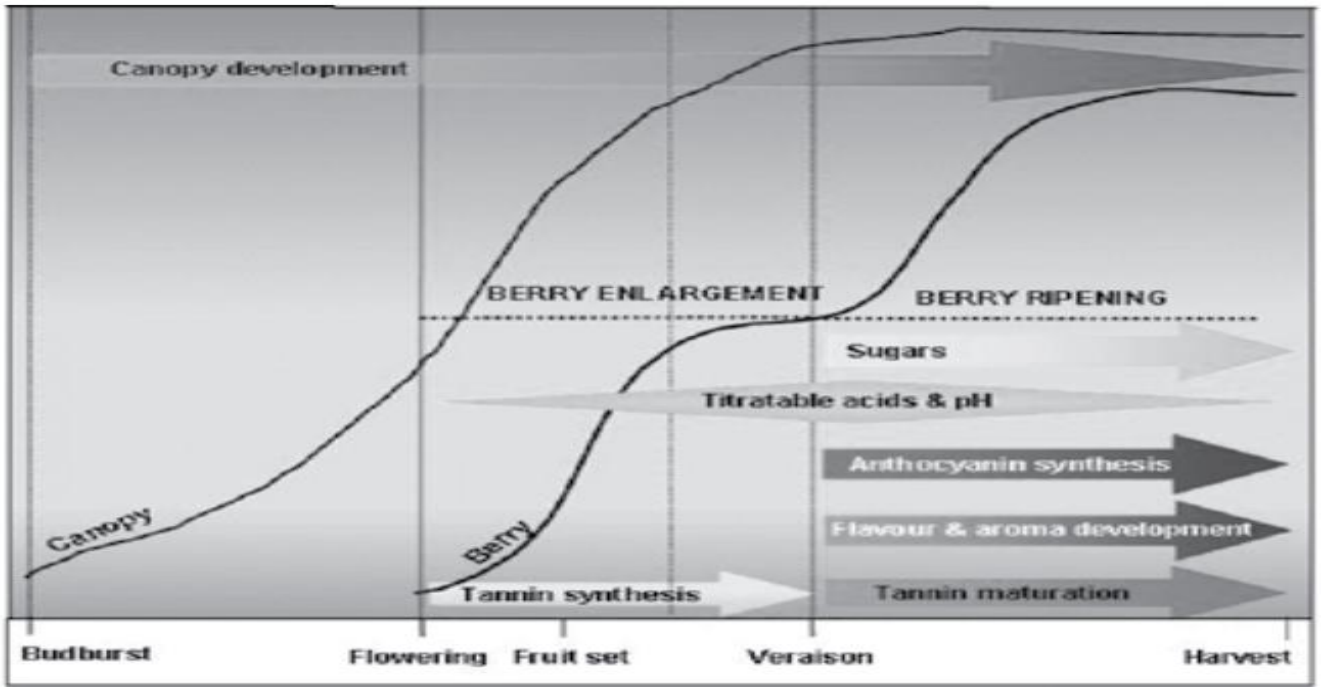


Figure 2.3: A graphical representation of canopy growth and grape berry development during a grapevine's growing season, source Adapted from Coombe, 1992; Coombe & McCarthy, 2000.

Figure 2.3 is a graphical representation of canopy growth and grape berry development of a typical wine grape during a grapevine's growing season. Bud break will occur in spring and harvest will occur in autumn. During this period a vine will have times when it needs more water than at other times. It is critical between budburst and fruit set for example to make sure the vine is content. Water stress should be avoided to ensure optimum flower retention and fruit set during this stage, and warmer temperatures and high soil moisture from sufficient precipitation or irrigation is needed to stimulate growth in the vine (Chalmers, 2012; Araujo *et al*, 2016). Between fruit set and harvest, the vine can handle moderate water stress without many negative implications, although berry size may be reduced with water stress during this period. Around veraison, severe water stress can delay ripening, as it causes a reduction in sugar accumulation. Post-harvest is another sensitive time for vines, as this is when they need to accumulate reserves for the following season, before entering into the dormant stage. The more severe the water stress, the faster the vine drops its leaves, and the fewer reserves will accumulate. Water stress during this period is dangerous as it restricts growth symptoms in the spring, especially in the younger vines (Chalmers, 2012). The amount of water required however at different stages of grapevine growth will depend on the cultivar, rootstock, and terroir, as well as crop load (NSW Agriculture 2004).

In the work of Romero, Fernández-Fernández & Martinez-Cutillas (2010), the works of McCarthy and Keller (1997) are referred to. This discusses how a decrease in water supply will affect a grapevine during the different phenological stages. They explain that a decrease in water supply early in the season, from fruit set to veraison to the beginning of the ripening phase in grapes, will reduce berry size and reduce the rate of shoot growth. They also refer to the works of Kennedy (2000), who discusses how a decrease in the water supply after veraison and during fruit ripening, will increase the biosynthesis of anthocyanins and other phenolic compounds.

Humidity, precipitation in addition to irrigation, has a critical role to play in determining the quality of grapes. The species Vitis vinifera is a hardy species and can survive in semi-arid climates. The grapevine has developed physiological and morphological mechanisms, which help the vine to survive under conditions of water deficits (Rayees *et al*, 2013). Moderate water deficits can cause the quality of grapes to increase. Smaller grapes are produced under dry and hot conditions, and these have more intense colour and flavour. There could also be an increase in total soluble solids, total anthocyanins, and phenolic concentrations, however there may be a reduction in titratable acidity in red and most white grape cultivars. The exceptions are Muscat and Sauvignon Blanc, which showed no change in total soluble solids (Mirás-Avalos & Intrigliolo, 2017). If the water stress to the plant is too severe, it will lead to a decrease in quality and could lead to the vine eventually dying due to the lack of water. Furthermore, the minimum water required for the vine to survive will vary between cultivars and rootstock used (Chaves *et al*, 2010). The timing of irrigation or precipitation will also influence the quality of the grapes.

Berry size, total anthocyanins, and phenolic compounds impact the quality of grapes. Wine grapes, both red and white cultivars that are smaller in berry size, are normally of higher quality. These berries generally have higher sugar concentration and are firmer, as well as having more intense skin colour compared to wine grapes

that are larger in size (Matthew & Vuzzo, 2007). An increase in total anthocyanins and phenolic compounds can also be linked to a higher quality grape, especially in red wine cultivars (Romero, *et al*, 2010).

2.2.3 Droughts

In Donald A. Wilhite's book Drought, he defines a drought as being "the consequence of a natural reduction in the amount of precipitation received over an extended period, usually a season or more in length, although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event. Drought is also related to the timing and the effectiveness of the rains (i.e. rainfall intensity and number of rainfall events). Thus, each drought year is unique in its climatic characteristics and impacts".

Droughts are considered one of the worst hazard events by characteristics, and their impacts can last for numerous years, cover a large geographic area, can affect a large number of people, can cause severe economic loss and can have a devastating long term impact on a country (Wilhite, 2000). The causes of drought are difficult to pinpoint, and even though technological advances have allowed climatologists the ability to predict the occurrence as well as the severity of the future drought, it is still difficult to prepare for such an event. Drought can occur in both low rainfall as well as high rainfall areas, and can often be a reoccurring climatic event (Wilhite, 2000). Drought periods affect food security, especially in the less developed countries where a larger portion of the population relies on subsistence farming for food. Drought affects live-stock production as well as crop production, as they both depend on water to survive. Certain plants are more resistant to drought such as cacti and succulents, however most plants that produce food for human consumption are less drought resistant. There are certain exceptions, such as Vitis vinifera, which is considered to be drought-tolerant and can grow in semi-arid conditions (Becker, 2018). Even though wine grapes are more drought-resistant when compared to many other fruit-producing plants, they still feel the effects of severe droughts.

In 2016 a paper was published, by Araujo, Abiodun, and Crespo. Which investigated the Impacts of drought on grape yields in Western Cape, South Africa. Theoretical and applied climatology, 123(1-2), pp.117-130. which investigated the impact of drought periods on wine grapes in the Western Cape. The paper starts by discussing the history of droughts within the Western Cape in the last 100 years, and focuses on three main areas: Stellenbosch, Robertson, and Olifants River. In the last 100 years, there have been numerous periods of droughts, some more severe than others. One of the main drivers of the severity of drought in the Western Cape is the El Niño Southern Oscillation (ENSO). The ENSO cycle is a scientific term that describes the fluctuations in temperature between the ocean and atmospheric conditions, which cause reductions in rainfall in the Western Cape (AgriOrbit, 2018) Stellenbosch in particular had five major dry periods before 2015 (1993-1995, 1997, 2000, 2003-2005 and 2009) and two minor periods (in 1985–1986 and 2006-2007) with at least moderate droughts. The area of Stellenbosch however also experienced abnormal wet conditions, with moderate to severe wet periods during 1987, 1989, 1996, and 2001 (Araujo *et al*, 2016). The paper then discusses the relationship between grape yields and these drought periods and shows that there were three periods of significant yield deficit (1994, 1997–1998 and 2002) and one period of considerable yield surplus (2005–2009). This showed that normally there is a yield deficit for a year after a dry period. This is however

not always the case, as there are also periods when there was an increase in the grape yield during drought years such as in 2009. This was said to be due to the application of suitable vineyard management, such as additional irrigation and mulching, to counter the negative effects of these drought periods (Araujo *et al*, 2016). According to Camps and Ramos, during drought periods, the yield for wine grapes is reduced significantly, as there is a strong correlation between the decrease in rainfall and wine grape yields. Yield can be reduced by up to 30 kg/ha for each millimeter increase in the estimated water deficit, especially under certain conditions (Camps & Ramos, 2012).

The quantity or yield of a grapevine is also influenced by multiple factors; unlike quality, the yield is significantly easier to measure as it is not subjective and can be measured using quantitative data. An obstacle that arises however, when studying the relationship between drought and grape yields, is the use of an appropriate drought index to quantify drought intensity. This is because there is no universal definition or index for drought. In South Africa, the most commonly used drought index is the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). These indices can be used to detect the temporal and geographical extension of droughts and can be used to monitor droughts (Araujo *et al*, 2016). The SPEI is comprised of seven classes in which droughts can be categorized from extreme wet conditions (≥2) to extreme drought conditions (≤−2). The table below illustrates the seven classes in SPEI

Table 2.3: The seven classes of SPEI category

SPEI measure	Category and description
≥2	Extreme wet
1.5 to 1.99	Severe wet
1.49 to 1.00	Moderate wet
0.99 to−0.99	Normal
−1.00 to−1.49	Moderate drought
−1.50 to−1.99	Severe drought
≤−2.00	Extreme drought

Sourced from Potop, 2011

The Western Cape's last major drought prior to 2015 occurred in 2003 and lasted until 2005. The drought reduced the total grape yields by 11.06% across the Western Cape (SAWIS, 2005). The red wine grapes however experienced an increase in yield from 158050 tons to 197923 tons, in comparison to the white wine grapes which experienced a decrease in yield from 896591 tons to 740027 tons. The increase in red wine grape yields could have been influenced by the increasing number of certain red wine cultivars that had been planted (SAWIS, 2005). Certain areas were affected more than others, such as the Swartland region (Araujo *et al*, 2016). Certain farms had irrigation systems in place and did not see much change in the grape yields, however, the farms that farmed with dryland vineyards, that relied entirely on the rain to water their vines, experienced an average of 30% decrease in yield (Araujo *et al*, 2016). In contrast, 2015 was the beginning of one of the worst droughts in the Western Cape's history. As the drought got worse and water restrictions were put in place, farmers could no longer irrigate their vines as often, which led to a 20% reduction in total yield across the Western Cape (Pienaar & Boonzaaier, 2018).

2.2.4 Droughts' impact on sustainability

The impact of droughts needs to be considered in terms of environmental, social, and economic sustainability, as the impacts of drought affect all three of these aspects. When investigating the environmental effects of drought, it is clear to see that groundwater and quality of groundwater are directly affected. This can increase the salinity in the soil, which directly affects crop production. The decrease in the water supply can affect the soil's ability to support crops and it will also lead to an increased amount of dust due to dryness, as well as soil erosion. This can cause an overall decrease in soil quality (Ali, *et al*, 2017). The longer the drought lasts, the more severely the environmental conditions will be affected, and the greater the possibility that future crop production will be impacted by these conditions.

The social impacts that occur due to droughts are issues such as job losses and deterioration in people's physical and mental health, caused by a decrease in revenue. During the 2003- 2005 drought, the grape yields reduced, and this threatened more than 2000 permanent and seasonal jobs in the wine industry (Araujo *et al*. 2016). Once again during the 2015 -2018 drought in the Western Cape, more than 30 000 jobs were lost in the agricultural industry, with a large percentage coming from the wine industry. This was due to a reduction in revenue, that can be linked to numerous factors including the drought. The decrease in revenue resulting from decreased production has negatively impacted the mental and physical health of many farmers and has caused many farm labourers to lose their jobs, which is not sustainable in the long run (Alston, & Kent, 2004).

The economic impact of droughts is correlated in that the more severe the drought, the larger the economic impact will be. Drought generally decreases crop yields, which often leads to a decrease in revenue and profit for farmers. The 2003-2005 drought in South Africa caused an estimated 37% decrease in agricultural revenue (Johnston, 2009). It has been estimated that the most recent drought in the Western Cape caused an estimated R5 billion loss in revenue between 2015 and 2018 (Kalaba, 2019). National Treasury spent over R3 billion on disaster relief for farms between 2015 and 2018, which could have been used in other sectors if the drought did not occur (Kalaba, 2019).

2.2.5 Soil properties

Another important aspect of terroir that needs to be considered when discussing the suitability of wine grape production, is the soil properties in a specific location. The term soil property is often used as an umbrella term for the makeup of soil including colour, texture, density, water holding capacity, infiltration rates, hydraulic conductivity, and the permeability of the soil. These are just a few of the terms that are associated with soil property (Myburgh, 2018). All of these terms affect the suitability of wine grape production in a specific location.

Howard Buffet once said "Soil is a living ecosystem and is a farmer's most precious asset. A farmer's productive capacity is directly related to the health of his or her soil. There are more living organisms in a tablespoon of highly organic soil than there are people on the planet". Soil has often been seen as the skin of the earth, however many people overlook the importance of soil. Soil is a mixture of minerals, water, air,

organic matter, and numerous other living organisms which form a natural medium in which plants grow and get their nutrients. This directly impacts the productivity of a plant (Keesstra *et al*, 2016).

A vine's rootstock is the link between the bearing cultivar and the soil, therefore the rootstock needs to be matched with specific soil properties in order for the bearing cultivar to grow. Soil's properties often interrelate with one another and need to be considered as a whole. The first characteristic of soil that needs to be broken down is the concept of soil texture. This refers to the size of the particles in the soil, which can be broken down into three main categories: fine, medium, and coarse. These give rise to the three main groups of soil from which most soils form. These are clay, which has fine particles, silt which has medium particles and sand, which has coarse particles (Moeys, 2018). Soils are categorized according to their texture using a texture triangle, which can be seen in Figure 2.4. The soil texture triangle is used to subdivide soils up into their different types, according to their percentage make up. Sandy loam for example, can be recognized as having roughly 70 percent sand and 15 percent clay, which can also be identified in figure 2.4 (Groenendyk *et al*, 2015).

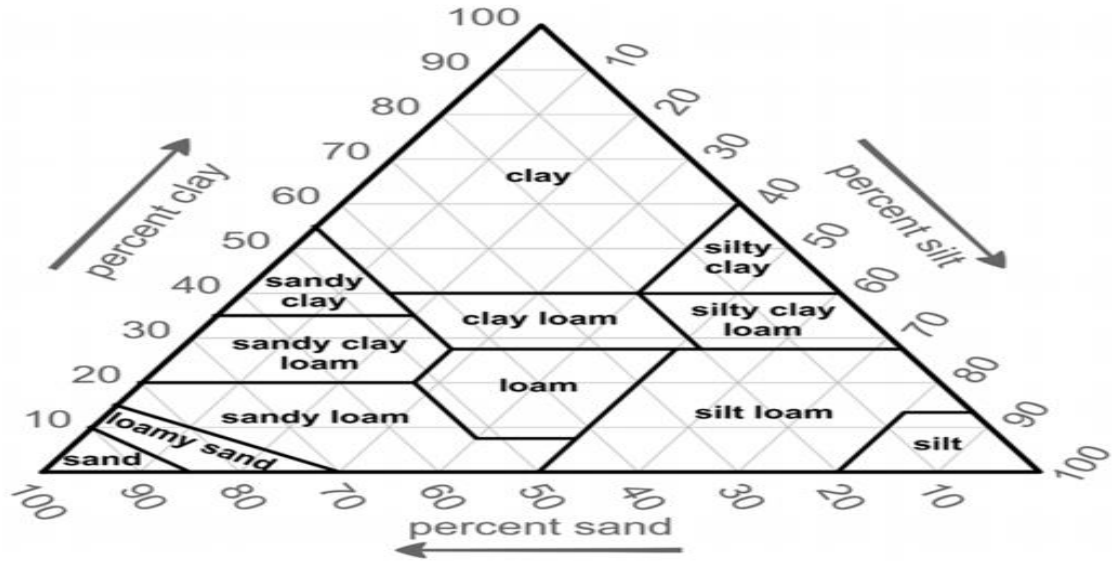


Figure 2.4: The USDA soil texture triangle, sourced from Groenendyk *et al*, 2015.

Once the soil texture has been determined, a viticulturist will then be able to decide what rootstocks to use for a block of vines. A rootstock, for example, such as 101-14, prefers a soil texture with a high clay percentage, whereas an O39-16 rootstock prefers a soil texture that is categorized as a coarse sandy soil (Lambert *et al*, 2008). Once the soil texture has been matched, a viticulturist can match the rootstock to climatic conditions. A O39-16 for example scores poorly in terms of drought resistance; this make sense as coarse sandy soils are considered the worst type of soils during the drought – they have poor water holding capacity and high hydraulic conductivity, which will be discussed in more detail shortly (Hacke *et al*, 2000). Finally, they see if the bearing cultivar is suitable to be grafted onto that specific rootstock. The roots from a rootstock generally stay within the first meter of soil from the surface, although they can be found at a depth of up to 6 meters, and

this means that the first meter of soil needs to be analysed in terms of texture, as it is the most crucial for the vines root development (Serra *et al*, 2014).

The soil density can be linked to the soil makeup, and directly affects root growth, as well as infiltration rates. The denser the soil the higher the probability of the soil having compact layers, which restrict both root growth and infiltration rates. There is also a strong relationship between wine grape productivity and the root development (Lanyon *et al*, 2004). Soils with a high clay content tend to have compact layers which restrict root growth as well and water penetration, due to the very fine particles found in clay. During drier years compact layers often form on the soil surface, which increases runoff and causes the impact of the drought to be more severe (Myburgh *et al*, 1996). There are three main ways to reduce the possibility of compact layers forming; either adding gypsum, lime or by increasing the organic matter in the soil through mulching and cover crops (Lanyon *et al*, 2004; Busscher *et al*, 2000).

The soil's water holding capacity impacts the productivity of wine grape production during years with above-average rainfall, and even more so during drought years. The soil's water holding capacity refers to soil's ability to firstly absorb as well as retain water, making it available to plants roots (Adamu & Aliyu, 2012). Soils that can hold substantial amounts of water are less subject to leaching, in addition to the loss of nutrients. Soils that are made up of smaller particles such as clay generally have a larger soil water holding capacity compared to soils such as sand that have courser, larger particles (Myburgh, 2018). In 1994 three Canadian researchers investigated the impact of soils with different water holding capacities on wine grape production. Their results showed that a reduction in the soil’s water-holding capacity tended to increase berry weight and soluble solids concentration but reduced lateral shoot growth under average rainfall conditions (Reynolds & Naylor, 1994). Once water stress was applied to the vines, the soils with lower water holding capacity were impacted more than soils that had a better water holding capacity, such as clay. With the added water stress, soils with a low water holding capacity tended to cause the largest reduction in lateral shoot length and lower shoot count, leaf size, and berry weights by the largest percentage (Reynolds & Naylor, 1994).

Hydraulic conductivity is another measure that can be used to determine the properties of the soil. The hydraulic conductivity of soil is also referred to as Ks. This is a measurement used to determine the ease with which water can flow through the soil from one place to another through the soil's pore network (Cooper, 2016). Soils that contain coarser textured material, such as gravel or sand, will have a higher Ks value than soils with finer-textured material makeup, such as clay. This is due to the fact that the particles are closer together, which makes the flow of water constricted (Cooper, 2016). During drier conditions such as droughts, a lower Ks value can be dangerous for grapevines, as there is less water available and less water movement in the soil. This means water might not be getting to the roots, which can cause water stress to be amplified (Homaee *et al*, 2002).

Soil infiltration and soil permeability work closely together and are often seen as being interchangeable. There is however a slight difference between these two terms. Infiltration refers to the movement of water into the soil, whereas permeability refers to the downwards movement of water after it has infiltrated the soil's surface

(Myburgh, 2018). Soils with finer textured material makeup, such as clay, have lower infiltration rates as well as lower permeability. This means that if the soil surface contains a larger amount of clay, infiltration will be low and runoff will occur. During a drier year, higher infiltration rates and high permeability is ideal, as it means the small amount of water that is available can get to the roots of the vines to decrease the vine degree of water stress. If it was to rain during a drier period and runoff occurred due to low infiltration rates, a vine will receive less water than if the soil had a high infiltration rate. This would mean that it would remain in a water-stressed environment (Ritchie, 1998). The best way to increase infiltration rates is to either increase organic matter on the soil surface through mulching or cover crops, or by making sure the soil surface is not compacted by applying gypsum or lime (Olson *et al*, 2013).

Evapotranspiration is the combination of both evaporation (when a liquid is converted to vapor and is removed from a surface/object as a vapor) and transpiration (when vaporized liquids, contained in plant tissues are expelled into the atmosphere) (Allen *et al*, 1998). Evapotranspiration predominantly occurs from a plant's roots and leaves. Both evaporation and transpiration rates are influenced by numerous factors such as soil texture, radiation, air temperature, humidity, and wind speed, for example, soils with a courser textured material makeup such as sand, tend to have a higher infiltration rate. However, they also have higher soil evaporation rates. The reason for this is that courser soils such as sand have a lower water holding capacity and are more permeable and tend to dry out faster than finer-textured soil such as clay (Myburgh, 2015). During the drier years therefore, it is beneficial to have a top layer that has a high infiltration and permeability rate, followed by a layer that contains some clay to reduce soil evapotranspiration (Myburgh, 2015). More radiation in addition to higher air temperatures and higher wind speeds increases the rate of soil evaporation. During the drier years, it is beneficial to reduce soil evaporation rates, as it will reduce the water stress on the vines; this is necessary during severe drought conditions (Çolak & Yazar, 2017).

There are numerous ways a viticulturist can reduce soil evaporation, however not all of them are economically feasible. One way to reduce soil evaporation is by reducing wind, which can be achieved by the use of windbreaks or moving from slanted trellis systems to using vertical trellis system (Myburgh, 2018). Another way to reduce soil evaporation is by using mulches or frequent shallow tillage around the base of the vines. Mulching is one of the best ways to reduce soil evaporation as it covers the soil surface and reduces the exposure of the topsoil layer to the atmospheric conditions such as radiation. It also restricts soil temperature from rising during the summer months, which also reduces soil evaporation (Myburgh, 2018). In 2015 a study was published that illustrated the impact that different quantities of mulch will have on soil evaporation. The study comprised of four different mulching regimes; the first test was the control test where there was no mulch added to the soil. In the second test 907kg of spread mulch was added per hectare, in the third test 9070 kg of mulch was added per hectare and in the final test 18140kg of mulch was added per hectare. All the tests took place under conventional tillage without any crops in the ground (Burt *et al*, 2005). The results from the four different tests can be seen in table 2.4.

Table 2.4: The effect of soil mulch on average daily soil evaporation

Test number	Average daily soil evaporation (mm)	Percentage reduction in average daily soil evaporation (%)
Test 1 (no mulch was added)	1.9	-
Test 2 (907kg/ha of mulch was added)	1.7	11
Test 3 (9070kg/ha of mulch was added)	0.6	68
Test 4 (18140kg/ha of mulch was added)	0.3	84

Sourced from Burt et al, 2005

In table 2.4 it is clear to see that the thicker the layer of mulch applied per hectare, the larger the resulting percentage reduction in soil evaporation.Soil evaporation decreased from 1.9mm in the control test with no mulching, to 0.3mm when 18140kg of mulch was added onto the soil. Under normal conditions with average rainfall and irrigation system in place, evaporation is not such a big concern. However, during drought periods on dryland, reducing soil evaporation is key to reducing severe water stress to a vine, which would otherwise cause them to die (Gil *et al*, 2018). Increasing the layer of mulch is only economically viable if the mulch is readily available from a nearby source. However, the transport of mulch over a long distance is not cost-effective (Myburgh, 2018). This being said, during a severe drought, extra mulch could make the difference between a vine dying and a vine surviving, which would make it economically feasible, as the benefit will outweight the costs. It is much more costly to replace a block of vines, than to add some extra mulch to the soil.

2.3 Climate change

Climate change and global warming are two topical issues in the 21st century. In 2019, a 16-year-old girl by the name of Greta Thunberg, reignited the conversation of climate change when she delivered a speech at the U.N. Climate Action Summit. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as being “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer” (IPCC, 2012). Climate change is associated with a change in climatic conditions, for example, an increase in average rainfall or an increase in the average daily temperature over the last ten years. Measuring climate change is simple, however predicting future climatic changes is more complex (Xie *et al*, 2019). Climate change can impact a country’s society, economy, and the environment in many ways, and needs to be monitored continually to address the problem.

In South Africa’s second National Climate Change Report published in 2017, climate volatility and climatic extremes are the two biggest issues discussed. Water was also mentioned as being the most prominent area through which the impact of climate change is being felt in South Africa. Water quality and water availability are two of the major areas of concern which South Africans will be faced with over the next decade. From 2000 to 2015 there has been a shift in rainfall patterns across the country, with some areas receiving more rainfall than usual and other areas are receiving less. Certain provinces such as KwaZulu-Nata and parts of Mpumalanga, have seen more severe storms and floods, whereas other provinces such as the Western Cape has been suffering from extended drought periods (Dea, 2017).

Climate change impacts the agricultural sector directly as it affects primary production directly, which impacts the whole of South Africa. Even though agriculture's share of the GDP was around 2,2% in 2017 (DAFF, 2018),, the agricultural sector is an important part of the economy, as it provides employment, especially in the rural areas, and is a significant earner of foreign exchange. The agriculture sector also has an indirect role in the economy, as it forms a large number of backward and forward linkages with other sectors (DAFF, 2018). Climate change, such as a decrease in rainfall or an increase in temperature, can therefore be problematic for the whole country. Climate change can be beneficial for certain areas, for example, an increase in rainfall in parts of the Karoo would be welcomed, however, in general, it has more negative impacts than positive ones (UNICEF, 2011).

When looking at climate change from a farmer's perspective, the focus tends to be on trends in both rainfall and temperature. A long-term trend such as a decrease in rainfall or an increase in temperature, will directly impact yields. This will affect the farmer's revenue as well as profits. The only way farmers can stay ahead, is by monitoring climate change continually, forecasting likely outcomes and acting in mitigation of the event, before it occurs. One of the best ways to stay ahead is through scenario development. An area such as Burgundy is known to produce some of the best Pinot Noir in the world as their terroir is almost perfectly suited for the production of good quality Pinot Noir grapes. An increase in temperature in Burgundy could be catastrophic for farmers in the area that grow Pinot Noir grapes (Jones, 2007). Should the average growing season temperature increase by one degree Celsius, there will be no major impact for Pinot Noir or Chardonnay grapes, however it will impact cultivars such as Pinot Gris negatively. Should the average growing season temperature increase by three degrees Celsius, it would potentially shift Burgundy into another climate region, from intermediate to warm according to the Winkler index. this will mean that the range of the red varieties that this region could grow will expand. Cabernet Sauvignon and Syrah would do better from the increase in temperature, but it will be too hot to grow certain cultivars. The increase in temperature will also allow Burgundy to start producing bigger, bolder red wines, but at the same time it would also cause Burgundy to lose its ability to produce the style of Pinot Noir for which it is known (Jones, 2007).

This increase in temperature will cause a cultivar such as Pinot Noir to go through its phenological events more rapidly, resulting in earlier and possibly higher sugar, and an increase in pH as the acidity is lost through respiration which will cause the wines to be unbalanced. It will also cause the alcohol levels to increase from an average of 12.3% to a possibly 13.9%. The unbalanced sugar to acid ratio will also have an impact on the aging potential of these wines (Jones, 2007; Van Leeuwen, & Darriet, 2016). By using scenario development, farmers have been able to prepare themselves for such events and have already begun changing certain vititcutural practices, in an attempt to mitigate against an increase in temperature.

Scenario development is also necessary for wine grape producers in South Africa, as they too are facing changes in climatic factors. According to research by Dr. Piotr Wolski, a researcher at the UCT's Climate System Analysis Group, there has been a decreasing trend in the average yearly rainfall over the last 84 years in the Western Cape Water Supply System (WCWWS) of around 17mm per ten years. This means that over 84 years, there has been a decrease of approximately 143mm in the average yearly rainfall, which equates to a

14% decrease in rainfall over the last 84 years. The decreasing trend can be seen in Figure 2.5. This is a graphical representation that was created from data compiled by taking the mean of three different weather stations in the Western Cape (Wolski, 2018).

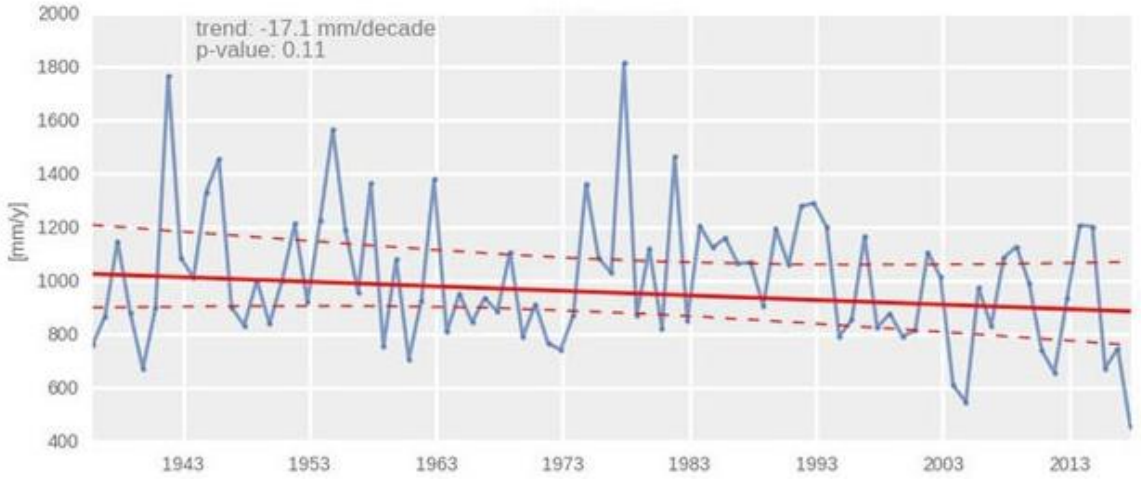


Figure 2.5: Average yearly rainfall from 1933-2017, sourced from Wolski, 2018

The next climatic trend that is seen as an indicator of climate change and needs to be monitored is annual mean temperature. Similar to annual mean rainfall, annual mean temperature fluctuates quite considerably between years. It is however the increase in annual mean temperature, which needs to be recognized and discussed. At the Nietvoorbij weather station in Stellenbosch, the annual mean temperatures were collected between 1967 and 2010. This data was then analysed and showed an increasing annual mean temperature over this period of just over one degree Celsius. This does not seem like much over 43 years, however a trend such as this needs to be monitored, because if this trend continues Stellenbosch might move into a different climatic zone in terms of the Winkler Index (Bonnardot *et al*, 2011; Keller, 2010). In table 2.5 it is clear that the increasing annual mean temperature over this period indicates that the mean growing season temperature, as well as the mean February and July temperatures, have also shifted. These are all important periods for a vine's productivity. The mean February temperature affects the production, as well as the ripening of the berries, and the mean July temperature influences the vine's ability to rest during the dormancy phase (Keller, 2010; Schultz, 2000).

Table 2.5: The mean temperature trends collected at the Nietvoorbij weather station between 1967 and 2010

Decades	1967-1970	1971-1980	1981-1990	1991-2000	2001-2010	Total change between 1697-2010
Annual Max Temp (°C)	22.1	22.5	23.0	23.1	23.1	+1.0
Annual Min Temp (°C)	11.1	11.6	11.7	11.8	12.1	+1.0
Annual mean Temp (°C)	16.4	17.0	17.3	17.5	17.5	+1.0
February Max Temp (°C)	27.4	27.4	28.4	28.7	28.9	+1.8
February Min Temp (°C)	14.8	14.7	15.9	15.7	16.2	+1.8

Table 2.6: (Cont.)

July Max Temp (°C)	16.1	17.2	17.2	17.4	18.1	+1.8
July Min Temp (°C)	7.0	7.6	7.8	8.0	8.4	+1.4
Growing season mean Temp (°C)	19.6	20.1	20.0	20.3	20.3	+0.7

Source Adapted from Bonnardot *et al*, 2011

In 2015 Gregory Jones, a research climatologist specializing in the climatology of viticulture, published an article that analyses the average growing season temperature range for each cultivar. It discussed what range each cultivar is best suited for; certain cultivars prefer cooler temperatures, whereas others prefer higher temperatures. A cultivar such as Gewürztraminer, which originates in Germany, prefers a temperature range of between 55-59 °F which can be converted into 13-15°C, whereas a cultivar such as Nebbiolo (an Italian red wine grape cultivar), prefers an average growing season temperature of 64-69°F (18.5-20.5°C). Understanding what the average growing season temperature range is for different cultivars can help to ensure wine grape producers achieve optimal production.

Figure 2.6: The Climate-maturity groupings based on growing season average temperatures, sourced from Jones *et al*, 2005

Figure 2.6 is a graphical representation of the climate-maturity groupings of different cultivars, based on their preferred growing season average temperatures. Table 2.5 and Figure 2.6 should be used in conjunction, to analyse whether certain cultivars are becoming less suited to the area, and what other cultivars will become more suited to the increased average growing season mean temperature. For instance, a cultivar such as Semillon might become less suited to the hotter growing season, and this will then create opportunities for cultivars such as Zinfandel and Nebbiolo. It is critical to monitor these trends every year, to make sure decisions are made in time. Trends such as these can be compared to Daniel Quinn's fable about the frog in boiling water; if a frog is put suddenly into boiling water, it will jump out, but if the frog is put in lukewarm water which is then brought to the boil slowly, it will not perceive the danger, and will be cooked to death. The same can be said about wine grape production, in that the increasing mean growing temperature which was suitable today might not be suitable in ten years' time, due to the increase in the average growing temperature.

The trend can be useful in all different facets of life, including when it comes to the production of wine grapes, although there are limitations as well. The limitations of average rainfall and temperature trends on wine grape production can occur in several ways. For instance, data that is collected from a nearby weather station will not be entirely applicable, which is why many wine grape producers are installing their own weather stations at the exact site of their vineyards. This will however only provide accurate weather trends for the last few years, which means there is no prior data for the trend to be analysed against (Alexander, 2016). Another limitation of these climatic trends is that they cannot be taken into consideration in isolation, as multiple factors affect the production of wine grapes (Jackson & Lombard, 1993). Nevertheless, climate trends such as average annual rainfall and temperature have an important role to play in guiding wine grape producers in terms of what cultivars are likely to be suitable to an area in the future.

2.4 Irrigation

Irrigation techniques date back around 8,000 years and were first used by the ancient Egyptians. They used the floodwaters of the Nile or Tigris/Euphrates rivers, and diverted the flood water to their fields to irrigate the fields before their annual crops were planted (Crossen, 1997; Chesworth, 1994). Irrigation systems and their schedules have been adapted and transformed quite considerably over the last 8,000 years. In the 21st century, irrigation is divided into two main categories - surface and sub-surface irrigation systems. Surface irrigation can be broken down into four subcategories: drip, micro-sprinkler, moveable sprinkler, and flood irrigation (Myburgh, 2018). Moveable sprinklers such as pivots are generally associated with annual crops, however drip irrigation is best suited for row crops such as vegetables, fruit trees, or vines (Fao, 1990). The number of vineyards under drip irrigation increased exponentially between 1997 and 2015, especially in the new world wine countries such as Chile, Australia, New Zealand, and South Africa. The reason for this sudden increase in drip irrigation is the improvement in technology as this has increased availability as well as feasibility, which has meant that farmers can improve productivity and open up marginal land (Myburgh, 2018; Fao, 2002). Numerous studies have investigated the impact of irrigation on the yield of grapevines, and many of them have come to the same conclusion, that irrigation of any sort can increase the yield of a grapevine. This

is not however the objective for all wine grape producers, as higher yields do not always mean good quality grapes (Romero *et al*, 2016; Cabral *et al*, 2018; Myburgh, 2018; Intrigliolo *et al*, 2016; Van Zyl, 1984).

Irrigation schedules in South Africa are designed according firstly to water availability and secondly the plant's needs. They are also adjusted according to the vine's growth cycle as well as terroir. During a drier year, water availability is often an issue, as wine grape producers generally get their water either from an irrigation scheme such as the Theewaterskloof Dam, or from on-farm water resources, such as storage dams. This means irrigation can be limited or even unavailable during drought periods (WWF, 2018). The limited availability of water during drought means wine grape producers need to use water more sparingly, and additionally, irrigation schedules need to be adapted to make sure vines only get irrigated when they need water. As discussed earlier, there are certain times during the growing season when irrigation is more beneficial than others, such as around bud break and during post-harvest (Chalmers, 2012).

Irrigation is beneficial for vines during severe water stress, which is when a vine faces an extended period of water deficit, and the evapotranspiration rate exceeds the root absorption rate (Van Zyl 1984). Irrigation can alleviate severe water stress to a vine, however the timing of the irrigation needs to be precise or the vine could die. Three main factors influence water stress on plants: evapotranspiration, the rate at which water moves from the soil to the roots, and the relationship between leaf water potential and soil water potential (Van Zyl 1984). One of the most reliable ways to measure the vine's water status is through the use of plant parameters, which are used to create a profile available water capacity (PAWC) This indicates the amount of water a certain area of soil can store and release to a vine (Van Zyl 1984).

Irrigation schedules need to be set up according to the terroir on which the vineyards are planted (van Leeuwen *et al*, 2018). As discussed earlier, different soil textures will have a different water holding capacity, as well as different evaporation rates. Fine sandy loam soil will have a larger water holding capacity and a lower rate of evaporation compared to a coarse sandy soil. This means that a coarse sandy soil will need more frequent irrigation compared to sandy loam soil (van Leeuwen et al, 2018). Figures 2.7 and 2.8 illustrate the difference between these two soils, in terms of water holding capacity and evaporation rates.

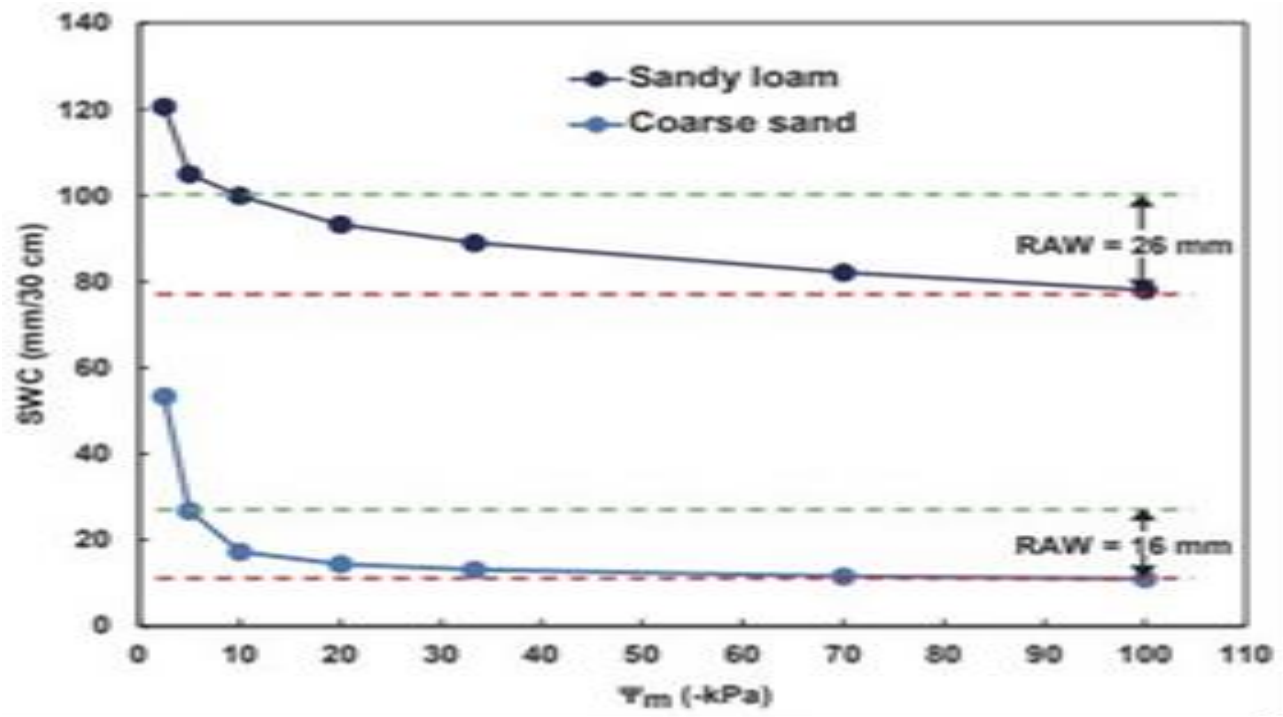


Figure 2.7: Water holding capacity of sandy loam vs coarse sand, sourced from Myburgh, 2018

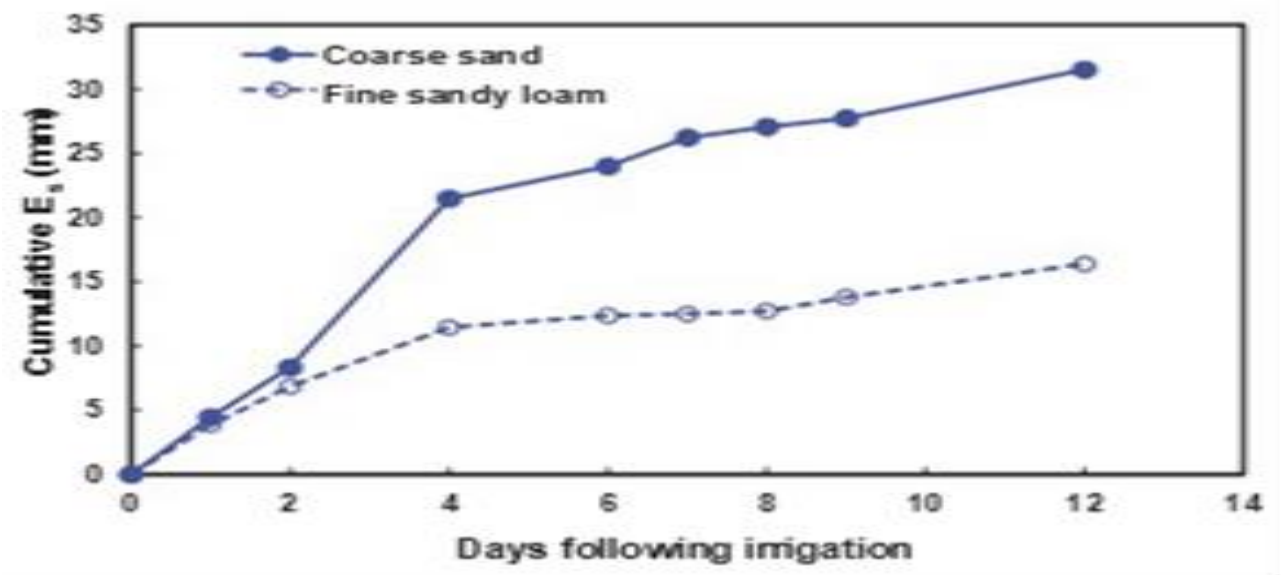


Figure 2.8: Evaporation rates of sandy loam vs Coarse sand, sourced from Myburgh, 2018

Before wine grape producers can go about installing irrigation in their vineyards, they first need to establish where they will be getting the water from. Water quality and availability are vitally important factors that will either make the installation or irrigation successful or not. The next factor that needs to be considered is the cost of installing the irrigation into the vineyards. According to James Briggs, the founder of Irrico, an irrigation specialist company, the price of drip irrigation will be between R5000- R20000 per hectare, and this depends on the type of drip irrigation that is installed. Subsurface drip irrigation is more expensive than normal drip irrigation, although it is considered to be a more direct form of irrigation. The total cost of installation will

also depend on the size of the area that needs to be irrigated, as the larger the area, the larger the pump will be to get the water across the entire area (James Briggs, 2020, Personal communication).

Once the cost of irrigation has been worked out, a producer needs to see if it is firstly feasible and secondly whether the benefits outweigh the cost of installing irrigation. During a severe drought, when producers have vines die from the water stress, the benefits of having irrigation will outweigh the costs. Droughts do not happen every year however, and during a year with above-average rainfall, irrigation for vines is often not necessary, as grapevines don't usually need much water to grow (Bowman, 2018). In 2018, a survey was conducted to determine the number of wine grape producers which use some form of irrigation. The survey found that areas such as the Orange River, Olifants River, Worcester and Robertson had 100% of their vineyards under irrigation, whereas in areas such as Stellenbosch, only 88% of wine grape producers had some form of irrigation. Durbanville and the Swartland only had 59% and 45% of their vines under irrigation (Vinpro, 2019).

2.6 Cabernet Sauvignon as a cultivar

2.6.1 Background

Cabernet Sauvignon is a red wine grape cultivar that was created by an accidental crossing of two cultivars. This occurred sometime in the 17th century, and the cross was between a red Cabernet Franc and a white Sauvignon Blanc. In the 18th century it gained popularity because of its resistance to botrytis - a necrotrophic fungus that affects wine grapes and causes bunch rot. Nevertheless, its reputation continued to grow and it was named as one of the five noble Bordeaux cultivars, thanks to the success of the Bordeaux wine region, which often used Cabernet Sauvignon red blends (Wosa, 2020; Goussard, 2008). In 1920, Professor Abraham Izak Perold endorsed the Cabernet Sauvignon cultivar as a quality red wine grape cultivar, and strongly encouraged farms in the Stellenbosch region to plant it. In 1990 it was the 8th most planted cultivar in the world, and by 2010, it became the most planted and most popular cultivar (Wine Searcher, 2020; Goussard, 2008). Cabernet Sauvignon is also the most extensively planted red wine cultivar in South Africa and Stellenbosch has the largest area under production, followed by Paarl, the Swartland, and then Robertson (Wine Searcher, 2020).

2.6.2 Cultivation characteristics

Cabernet Sauvignon is a relatively hardy red wine grape cultivar, and grows well in areas with a warm average growing season temperature of around 17-19 °C, from veraison to harvest. Cabernet Sauvignon prefers warm day and cool night temperatures, as this optimizes colour and flavour synthesis. Cabernet Sauvignon prefers soils with a medium to high potential (Goussard, 2008). Cabernet Sauvignon is known to have a medium to low production yield of around six to twelve tons per hectare, however it is relatively resistant to yield fluctuation, although areas with sufficient soil water are preferred. It has good resistance to botrytis rot but it is susceptible to downy mildew and Oidium, which is a type of fungus. It has also been said that it has a strong wind tolerance and is compatible with all commercially available rootstocks (Goussard, 2008).

In Stellenbosch, the bud break for Cabernet Sauvignon normally occurs around mid-September, about three to seven days after Cabernet Franc. Flowering tends to begin in the first two weeks of November and is when the

vine is at its most sensitive. Veraison occurs around the beginning of February and harvest tends to occur a month and a half later, around mid-March. This being said, virus infected vines, for example vines with leaf roll, will generally experience a delay in ripening (Goussard, 2008; Wosa. 2020). Ripe berries have a sugar concentration of around 22-24 Degrees Brix (°B) which is a scale that measures the total soluble solids which constitutes the grams of sugars per hundred grams of juice. They also tend to have an average acidity of around 6.6-7.1 grams per litre (g/l). The berries tend to be small and round, weighing in at around two grams each. Each berry is comprised of approximately 5% seed, 15% skin, and 80% flesh (Nuzzo & Matthews, 2005). Cabernet Sauvignon when fully ripe tends to be dark black and has a relatively thick skin that protects the berries from wind damage. The berries generally have a flavour of raspberries, liquorice, chocolate, green peppers, and even grassy characteristics (Goussard, 2008). Cabernet Sauvignon tends to have small bunches with a cylindrical to conical shape.

2.7 How is quality measured

Before quality in wine grapes or wine can be measured, one first needs to define what quality is and by what parameters quality is measured. According to the International Standards Organization (ISO), quality can be defined as “a degree to which a set of inherent characteristics fulfills requirements” (ISO 9000, 2005). There is a large number of different agricultural products that all have certain quality parameters, and these are used as a guide to determine the quality of each of these products. Quality will always be slightly subjective, as each consumer's understanding of quality is different (Moreda *et al*, 2011). An example in citrus is that the size of the fruit will determine what grade it will be. Fruit over a certain size is often regarded as lower grade fruit, however, countries like China and Japan have consumers than enjoy the larger citrus fruits and do not regard it as lower grade fruit (Moreda *et al*, 2011).

There has been an increase in the application of standards and certifications to different activities within the agricultural food sector, which has been influenced by the end consumer as well as by certain powerful retailers. The application of certain standards and certifications can monitor, as well as improve the quality of a product and these standards and certifications also help to regulate industries and improve consumer health and safety requirements (Webber and Labaste, 2011). People along the value chain are starting to realize that standards and certification are not only a condition for market access, but they also provide a powerful way to compete for market share, as well as helping products obtain price premiums in the market. Certification, such as fair trade, bird-friendly, or certified organic products, can open up a specific portion of the market, as these certificates show how the product was made, and act as a measurement for the quality of the product (Webber and Labaste, 2011).

Most countries have fruit and vegetable marketing standards that have been established to indicate certain quality criteria that fresh-market products have to meet. The European Communities (EC) Commission Regulation 1221/2008 (the Regulation) was created to give a universal marketing standard, which certain products need to meet for them qualify to be exported and sold in different retail stores (Moreda *et al*, 2011). The Regulation covers 26 different fruits and vegetables including apples, apricots, artichokes, asparagus,

citrus fruit, kiwifruit, lettuces, peaches, nectarines, pears, and strawberries (Fao. 2008). The Regulation also provides minimum quality requirements that cover most fruit and vegetables, and these requirements are as follows:

- The product needs to be intact
- products affected by rotting or deterioration such as to make them unfit for consumption are excluded
- clean, practically free of any visible foreign matter
- practically free from pests
- practically free from damage caused by pests affecting the flesh
- free of abnormal external moisture
- free of any foreign smell and/or taste

Fruits that get processed, such as citrus or wine grapes for their juice, are graded slightly differently as their appearance is trivial. Processed products such as orange juice and wine need to be graded before the raw product is processed, and then again once the product has been processed. With products that are processed appearance might not always be significant. However certain seemingly insignificant physical properties may have a severe effect on the quality of the end product. A simple example of this can be observed with wine grapes which are made up of three major types of tissue: flesh, skin, and seed. The majority of the juice that will be turned into wine, is extracted from the flesh. The composition of the grapes will contribute to overall wine composition and the style of wine can therefore be influenced by simply changing the berry size. Smaller berries will have a higher proportion of skin and seed-derived compounds (Kennedy, 2002).

The processing of citrus and wine grapes cannot be viewed in the same way. With citrus the lower grade fruit is sent for juicing, as low-grade citrus fruit cannot be sold for the same price as high-quality citrus fruit. The price for the juice will however be higher than the price that is commanded in the market by low-grade citrus fruit, whereas high-grade citrus will command a higher price than if it was processed for juice (Fao. 2001). Wine grapes do not have the same qualities as even the high-quality grapes get processed. Wine grapes are very different from table grapes as they are smaller, stippled with seeds, have thicker skins, and have a different chemical profile compared to table grapes (Di Genova *et al*, 2014).

With wine grapes, quality is once again a subjective concept, as each wine producer will look for different criteria. Each producer has a unique style of winemaking, and they want grapes that fit those styles. It is also subjective due to individual interpretation and trends, and may also depend on commercial targets, market constraints, processing capacity, and other factors (Gil-Muñoz *et al*, 2018). This being said, wine grapes can be seen as a homogenous product, as it is difficult to distinguish between grapes from different suppliers. However, once the grapes have been processed and turned into wine, the wine is no longer a homogenous product, as wines from different estates are seen as being unique. This means that even if the quality of the grapes increases, the price does not change by much, as quality can be seen as a subjective term (Mitcham *et al*, 1996).

Optimal ripeness, fruit maturity, and quality are three terms that are often used interchangeably, however it is important to understand the difference between the terms. Optimal ripeness and fruit maturity occur at a specific stage during the lifecycle of the grape. Optimal ripeness refers to a stage of growth or development, where a fruit is ready to be harvested as the colour, flavour, and texture of the fruit are fully developed. Fruit maturity refers to when the fruit has reached its maximum size but does not mean it is ready for harvest as the colour, flavour, and texture of the fruit might not yet be fully developed. Optimal ripeness and fruit maturity do not always happen at the same time as fruit maturity generally occurs before optimal ripeness (Cancler, 2012). Fruit ripeness is often used as a proxy measure of fruit quality, as fruit quality is considered to be at its highest when fruit are at their optimal ripeness (Kader, 1999). Fruits such as wine grapes have two different periods of ripeness, that don't always occur at the same time - phenolic ripeness and sugar ripeness. Phenolic ripeness refers to the stage when the grape tannins and phenolic compound development is complete, and sugar ripeness occurs when there has been a sufficient breakdown of acids and an accumulation of sugars. Grapes are generally harvested at sugar ripeness rather than phenolic ripeness, which can occur before sugar ripeness has occurred (Segade *et al*, 2008; Coombe *et al*, 1980).

The quality of wine grapes can be broken down by using certain proxy measures, which can be grouped into three main categories: firstly, physical aspects, secondly chemical composition, and finally sensory characteristics (Ferreyra *et al*, 2002). Under each of these categories, certain criteria can be used to indicate the quality of wine grapes, although each cultivar will have a slightly different range under which high-quality grapes can be associated. Grouped under physical aspects are criteria such as berry size, berry shape, number of berries per bunch, distribution of berries within the bunch, the shape of the bunch in addition to the overall health of the bunch (Ferreyra *et al*, 2002). Chemical composition is determined through a wide variety of tests and indices, such as the sugar accumulation, total acidity, berry pH, berry colour, total phenols, total anthocyanins, total tannins, seed lignification and pulp to skin ratio (Ferreyra *et al*, 2002; Azevedo-Opazo *et al*, 2001; Botes, 2009). The final category is a sensory evaluation which involves the taste and mouthfeel of the grape juice.

2.7.1 Physical aspects

The average size of grapes is the first parameter that needs to be analysed, in order to determine the quality of the grapes. In 2007, Matthews and Vuzzo published an article that analysed the berry size and yield paradigms on grape and wines quality. The articles were formed around two hypotheses: firstly, whether small berries make better wine, due to higher surface volume and higher concentration, and secondly if high yields means low quality as flavour compounds get diluted. They wanted to use these two hypotheses to try and prove whether there was a specific yield/ berry size threshold and that anything above this threshold would negatively impact grape and wine quality. It would also allow the producer better insight into what yield would be ideal for producing high-quality grape and wine. This knowledge would be fundamentally important to production decisions (Matthews & Vuzzo, 2007). In the findings of this article, it is shown that larger berries are less desirable, due to an increase in water diluting solutes, which decrease the concentration of the flavour profile. There were many different variables of terroir however that caused the grapes to be a certain size and depending

on which variables had the biggest role to play. Figure 2.9 is a graphical representation of the theoretical relationship between relative berry size or yield and relative wine quality.

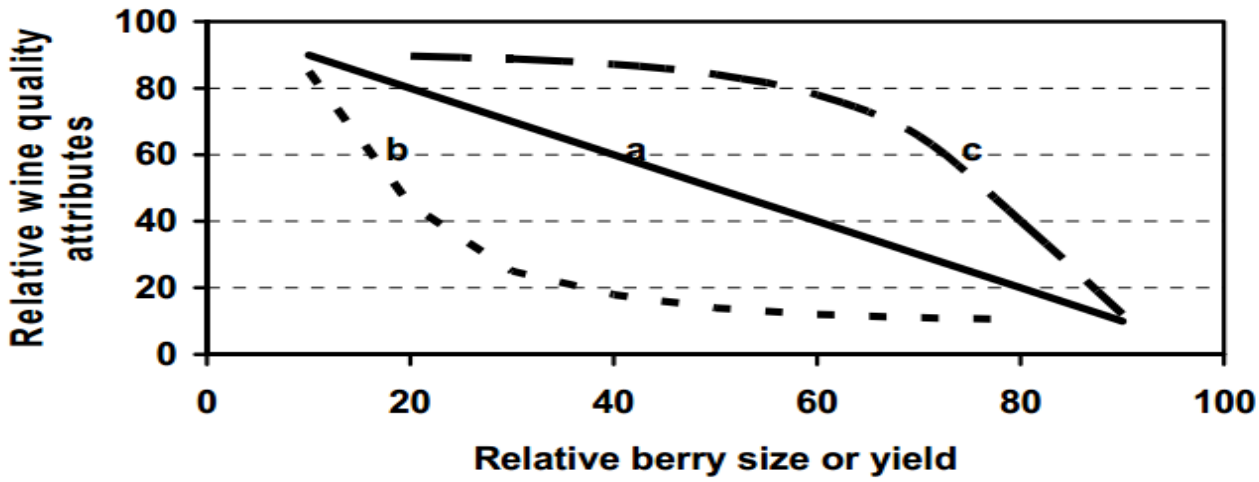


Figure 2.9: Wine quality response curves to the increase of berry size and yield, sourced from Matthews & Vuzzo, 2007

Figure 2.9 gives a good indication of how berry size or yield can affect the wine quality, by looking at three different scenarios. All three scenarios indicate that as the berry size /yield increases, so the wine quality decreases, scenario B causes this to occur at a faster rate and scenario C at a slower rate whereas scenario A is so called average.

In a study conducted in 2004 by Roby and Matthews, the relationship between berry size and the sugar concentration, in addition to the sugar content was examined. The results from this study indicated that as the size of the berry doubled, the sugar content increased by 70%. As the size of the berry doubled the sugar concentration decreased by approximately 10%, which is due to the berry becoming more diluted as its size increases (Roby & Matthews, 2004).

The shape of the berry is influenced by the grape's structure, as well as the growing season's conditions, although the shape will be cultivar specific. This being said, consistency is key when it comes to berry size, as a bunch with consistently sized berries will be considered higher quality than a bunch with inconsistently sized berries (Norrie *et al*, 2001). The shape of the bunch will also influence the quality of the berries. For example, Cabernet Sauvignon tends to have small bunches with a cylindrical to conical shape, and if the bunch shape is not consistent across the block then the grapes will not ripen uniformly (Goussard, 2008).

The distribution of berries within the bunch and the overall health of the bunch, go side-by-side. Bunches with a loose distribution of grapes allows better airflow through the bunch and allows more sunlight to reach the middle of the bunch. This means that grapes ripen more consistently, and also decreases the chance of damp pockets forming, which can lead to an increase in disease and fungi pressure (Molitor *et al*, 2011). Bunches with very compact berry structures tend to have lower overall health, as they are more susceptible to rot as well as berry burst, which means that less dense bunches generally have better quality grapes (Molitor *et al*, 2011).

2.7.2 Chemical analysis

Chemical analysis can be broken down into a wide variety of tests and indices such as sugar accumulation, total acidity, berry colour, total phenols, total anthocyanins, total tannins, seed lignification, and the pulp to skin ratio (Ferreyra *et al*, 2002; Azevedo-Opazo *et al*, 2001; Botes, 2009). These tests and indicators can be used as a proxy to measure quality. Many of these tests are complex and intricate; however they need to be dismantled for the reader to understand how they can be used as a proxy measure for quality (Ferreyra *et al*, 2002).

Sugar accumulation in grapes begins to increase after veraison, as sucrose is moved from the leaves and begins to accumulate in the grape as fructose and glucose. During the process of fermentation, sugars from wine grapes get converted by yeast into alcohol and carbon dioxide (Jordão *et al*, 2015). Measuring sugar accumulation is also a method to determine when the grapes are ready to be harvested. Sugar accumulation is measured with either a refractometer or a hydrometer, and the measurements are expressed in degree Brix (Jordão *et al*, 2015). In Cabernet Sauvignon, the appropriate sugar accumulation at harvest should be between 22-24 °B (Goussard, 2008). The ratio of glucose to fructose is also important, as fructose is much sweeter than glucose. During fermentation, glucose is typically consumed at a faster rate than fructose. When there is a fructose/ glucose ratio of more than 1:1, there is an increased chance of stuck fermentation occurring and unlike acid, glucose cannot be added to fix the issue of a stuck fermentation. The only way therefore to fix stuck fermentation is by using Saccharomyces cerevisiae wine yeast, which is more expensive than normal wine yeast (Amerine & Thoukis 1958; Gafner & Schütz 1996). Having a high fructose/ glucose of above 1:1 can consequently be seen as a negative parameter of grape quality.

Total acidity is made up mainly of malic acid and tartaric acid. Total acidity reaches a peak at veraison, and then starts to decline from post veraison when sugar accumulation begins to increase. Malic acid decline tends to be rapid at first, whereas the tartaric acid decline is more gradual (Brown, 1981). The first way in which acidity can be measured is by measuring the tartaric acid (TA). TA is expressed in either % TA or g/L. In Cabernet Sauvignon, a TA measurement of 6.6-7.1 g/l is regarded as being acceptable (Brown, 1981; Winkler *et al*, 1974; Goussard, 2008). An alternative measure of acidity is measuring the berry PH, which can be used as a parameter for quality. Cabernet Sauvignon has a desired pH range of 3.4-3.6; however, if the juice pH is above 3.6, it can be rectified in the cellar by adding extra acid, such as tartaric acid. This process can be expensive however, so the other option would be to blend the wine with wines that have lower pH values (Winkler *et al*, 1974).

Phenolic compounds, such as total phenolics, total anthocyanins, flavonols, catechins, and other flavonoids, have an important role to play in wine quality, as they contribute to the sensory characteristics of wines, particularly colour flavour and astringency (Yıldırım, 2013). Statistical analysis was conducted on Australian Shiraz and Cabernet Sauvignon wines, which has shown that there is a positive trend toward higher wine grade allocation of wines that had higher concentrations of total phenolics (Mercurio *et al*, 2010). Total tannins and tannin structure is another key parameter of quality, especially in red wine cultivars such as Cabernet Sauvignon. Tannins play a critical role in alleviating wine colour and contributing to the mouthfeel of the wine.

In red wines, tannin concentration and structure have a positive relationship to red wine quality, and also improve the age-ability of red wines, such as a Cabernet Sauvignon (Mercurio *et al*, 2010).

Berry colour, especially in red wine grape cultivars, is an important parameter by which quality can be assessed. The level of anthocyanins in the skins of grapes impacts the colour intensity and hue of red wines (Boss *et al*, 1996). Measuring anthocyanins is much more complex than measuring total sugar accumulation or TA, and samples need to be sent to a laboratory. Total anthocyanins are measured using mg/L and grapes that are high in anthocyanins tend to produce darker red/purple wines. A full-bodied red wine typically has around 600-800 mg/L but can in some cases be higher than 1500 mg/L (He *et al*, 2012). Cabernet Sauvignon grapes naturally produce full-bodied red wines and have around 750-850 mg/L of anthocyanins (Ferreyra *et al*, 2002). A cultivar such as Cabernet Sauvignon is regarded as being of a higher quality when it has more total anthocyanins (He *et al*, 2012; Mercurio *et al*, 2010).

The pulp to skin ratio of wine grapes is another parameter that is used to indicate berry quality. Most red wine grapes consist of 5% seed, 15% skin, and 80% flesh. Within the thin grape skin, there are numerous different components, including aromatic substances, potassium, and phenolic compounds such as anthocyanins, flavonols and catechins. The bulk of the grape is made up of the pulp, which is beneath the skin, where the grape juice comes from (Dharmadhikari, 1994). Smaller berries tend to have a larger skin to pulp ratio than larger sized grapes, as the size of the berry decreases, and the wine quality should improve. A slightly high skin to pulp ratio can therefore indicate better grape quality (Matthews & Vuzzo, 2007).

2.7.3 Sensory evaluation

The field of sensory science is a relatively new scientific field that has struggled to gain momentum as the subjects are human and use past experiences to explain their sensory inputs. Wine quality scales and measurements are dependent upon the judge's interpretation of quality. Nonetheless, there has been steady progress in emerging objective metrics of the sensory experiences (Matthews & Vuzzo, 2007). The main aim of sensory wine tasting is to determine the quality of the wine, by exploring its sights, aromas, and flavours, and compare the wine with what is in nature, as well as to describe the flavour and aroma profile of a particular wine. To sum it up in one sentence, sensory evaluation is used to explain what a wine tastes like, and to assess its overall quality (Santarosa, 2014). There are a couple of issues that arise with sensory evaluation because a taster is trying to quantify a fundamentally subjective experience. Not all people have the same preferences and palate, therefore two tastings from the same bottle of wine might be judged completely differently; each taster will have a different way of explaining the flavours and aroma profile of the wine, in addition to the overall quality of the wine (Santarosa, 2014). Wines are judged according to three main components: sights, aromas, and flavours. With sight, two main components need to be assessed and these are clarity and colour. Clarity can be described using terms such as:

- Brilliant (sparkling clear).
- Clear (free of visible solids but not sparkling).
- Dull (hazy but no solids).
- Cloudy (small particles can be seen floating in the wine) (Santarosa, 2014).

The colour of the wine also has specific terminology that is used to assess the look of the wine:

- Depth (the intensity of the colour)
- Hue (shade of colour)
- The colour must be appropriate to the wine type (reds are purple in their early life and become reddish-brown as they age/ white wines can go from very pale yellow to deep yellow gold) (Santarosa, 2014).

Aromas are assessed through the sense of smell, which is more sensitive than the sense of taste - the human nose can detect many more compounds at much lower concentrations. Aroma compounds need to be volatile and be light in density to be carried by air (Santarosa, 2014). Wine is swirled before it is smelled to get the aroma compounds airborne. Aromas are frequently described by comparing them to aromas of other products that have been smelled before, such as green grass, tropical fruit, or coffee (Santaros, 2014).

The final component of the sensory evaluation is taste, which is the consequence of the multisensory integration of touch taste and smell, which are perceived in the mouth and throat on contact with a substance (Lindemann, 1996). Taste is determined by the taste buds which are located at the tip and upper surfaces of the tongue. Taste buds send electrical impulses to the brain, which then processes them and compares them to things that have been tasted before (Santarosa, 2014). There are four principal tastes that humans use to categories substances and they are:

- Sweetness
- Acidity
- Bitterness
- Salty (not important in wine).

The temperature of the substance plays an important role in the sensory evaluation process, for example warmer temperatures cause the aroma in wines to become more intense, as it causes the aromatic compounds to become more volatile. Cooler temperatures cause wines to have an extra refreshing quality but diminish aroma (Ross & Weller, 2008).

As discussed earlier, wine quality is hard to define, and this is primarily linked to the lack of agreement on the term quality in general. People who study wine quality often refer to perceived wine quality, rather than just quality (Hopfer & Heymann, 2014). The perception of quality is built around two main dimensions, being extrinsic and intrinsic. Extrinsic factors consist of the grape growing and winemaking processes, and the drinkability of the product. The intrinsic factors focus on the drinking experience and comprise factors such as pleasure, flavour, aroma, and mouthfeel, as well as factors such as origin, variety, typicality and potential. These factors are typically associated with wine quality judges that are highly involved in assessing the perceived quality of the product (Charters and Pettigrew, 2007).

Extrinsic information, such as wine critic scores and labelling, can sway a consumer in terms of the wine's perceived quality. Studies have found that average consumers perceived quality of champagne and other wine

products differently when they were able to see the labels, compared to when they tasted the same products blindly (Hopfer & Heymann, 2014). Wine consumers, especially ones with a lower degree of wine knowledge, rely heavily on accredited experts as a source of guidance. They also rely on brand, awarded medals and wine articles in their purchase of specific wines, and base their perceived quality on these markers (Hopfer & Heymann, 2014).

There are numerous different wine competitions and wine rating agencies that assess the perceived quality of wine produced both internationally and locally. These different wine competitions and wine rating agencies do this through sensory evaluation. In South Africa alone, there are over ten different wine competitions, in which producers can enter their products. These competitions are as follows:

Table 2.7: Wine competitions in South Africa

1. Classic Wine Trophy (TAJ SA)	2. SA Sommeliers Selection
3. Juliet Cullinan Wine Connoisseur's Award	4. SA Terroir Wine Awards [National]
5. Michelangelo International Wine Awards SA	6. SAA Airline Awards
7. Nedbank Green Wine Awards	8. Six Nations Wine Challenge
9. Old Mutual Trophy Wine Show	10. Top 100 SA Wine Challenge
11. Regional Wine Awards	12. Veritas Awards

Sourced from Sawi, 2013

In these competitions, wines are tasted against each other, and the producers' names are not known. This is done to try to remove any biases, as neither the price nor the reputation of the producer should be able to influence the rating in any noticeable way. These wines are tasted by full-time wine professionals, who are familiar with specific standards of perceived wine quality (Sawi, 2013). Once the wines have been tasted, the scoring of these wines can commence by simply taking the tasters' opinion and applying a numerical system from which a score is derived for each product that has been entered into the competition. These competitions are used to give an objective method to consider the quality of a wine and are used by many consumers when deciding what wine to buy (Sawi, 2013).

One of the longest-standing wine rating agencies is the Platter's South African Wine Guide, which was established in 1978 by wine journalists John and Erica Platter. The first Platters Guide was published in 1980 and forty years later, the Platters' Guide is getting thicker by the year (Platter's, 2020). The South African Platter's Guide is comprised of wine reviews, winery profiles, and cellar door attractions and features hundreds of producers, as well as thousands of individual wines from different producers. The Platter's Guide serves as a wine guide rather than a competition. Each year a panel of expert tasters are selected to taste a wide range of wines from hundreds of producers. The first round of tastings take place as sighted tastings, so that the tasters can learn as much as possible about the producer and the wine's backstory. They are also given details such as site and climate, of the specific geography of the origin of the wine. Any product that scores over 93 points moves into the five-star tasting round, which is a blind tasting, and these wines are compared against one other within a specific category, for the ultimate accolade of five stars (Platter's, 2020).

Both wine competitions and wine rating agencies/guides have been designed to help objectively quantify the quality of wine and other wine-based products. However, the fact that wine is given a gold medal at a wine

competition or a five-star rating by a wine guide, does not mean everybody will judge the wine to be of high quality. After all, each person is different, and as already discussed, quality is a subjective term. Competitions and wine rating agencies/guides should rather be used as a recommendation, rather than an absolute standard of quality (Sawi, 2013; Hopfer & Heymann, 2014; Charters and Pettigrew, 2007).

2.7.4 The influence quality has on price

With most products, as the quality increases, so does the price. However, producers have recognised this relationship and often use price to try to get customers to believe that the products are of better quality, by the large price tag on the product. With wine, there are two points in the value chain where the relationship between price and value can arise. The first is if the grape producer sells grapes to a wine producer, and the second is when the wine has been bottled and labelled and is ready to be sold. Both these links in the value chain are influenced by extrinsic factors that influence the price (Hopfer & Heymann).

Wine grape quality assessments are a multifaceted topic, and they will vary significantly depending on certain factors, such as the winemaker, variety, location, and intended use of the grapes (Accc, 2019). As discussed earlier, there are numerous ways in which the quality of the grape can be assessed. However, it will still be a subjective measure. Each winery will have a unique way of approaching quality and assessing quality. Contracts between wineries and grape producers are used to clarify what price the winery will pay the grape producer for a ton of grapes. This is used to articulate the wineries' requirements concerning the quality of grapes produced, in addition to describing what characteristics they are looking for in the grapes (Fraser, 2003). A contract can be seen as a form of insurance to a grower, and it also provides incentives so that the grower can ensure that the necessary effort is taken to produce wine grapes of the specific desired quality. The contract needs to be designed in such a manner that a winery offers incentives to prevent neglecting the quality of the grapes, but also does not place the grower in danger of excessive risk, as weather conditions within a growing season cannot be controlled by the grower (Fraser, 2003). To ensure that the risk is spread between the two parties, contracts will normally contain a flat fee for the price of grapes, which is discussed before the growing season, plus different performance incentives, such as bonuses and penalties for the overall quality of the grapes (Fraser, 2003).

Pricing in a contract is a key component, and is often the determining factor on whether or not a contract is agreed upon. Numerous methods can be used within a contract to state how pricing will be determined for the grapes, and the most common methods are minimum price per ton of grapes, fixed price with CPI indexation to adjust according to inflation, market price with bonus and penalties included, spot price in addition to residual claims which is based on revenue generated from the sale of the wine (Fraser, 2003). Lower quality grapes are likely to receive market prices for the specific variety in a given location. Premium prices are often offered to grape producers with a good track record of producing quality grapes, for a consecutive number of years (Darling, 1999).

The second reason contracts are used, is to get an agreement between the grape producer and the winery, and to ensure that both parties have the same goal. Contracts can be designed in such a way so that they reduce the

issue of moral hazard and adverse selection and ensure that both parties enter into a fair agreement. If for example the grape producer knows that the vines were suffering from the leaf roll virus in the prior season, this might not be mentioned to the winery. If the contract is designed in order to cater for this kind of eventuality, it can mitigate these risks for the winery, by enforcing a penalty due to the grape quality failing to achieve certain parameters (Fraser, 2003). There are three main ways in which a winery can adapt the contract design so that their risk of moral hazard and adverse selection is reduced. The contract can state that:

1. A winery can monitor the grower effort: This can be done by visiting the farm where the grapes are being produced during the grape-growing period.
2. A winery can exert more direct control over vineyard practices, as well as by the timing of these practices. They can have input into what fertilizer should be used or decide on the timing of the irrigation schedule and the type of irrigation technology used.
3. A winery can measure the quality of grapes supplied and set out specific parameters concerning which specific viticultural practices should take place.

In certain situations, wineries purchase their grapes from a grape producer, based on long-term relationships. This transaction takes place with no written contracts, due to evolved mutual trust which has formed between the two parties over the previous seasons. The ever-changing business environment requires a contract to be in place, in order to mitigate risk as well as to be able to secure financial support. The contract can be designed around either quality or quantity, which will influence the way that the grape producer conducts certain viticultural practices (Fraser, 2003; Haughton & Browett, 1995; Scales *et al*, 1995). A larger portion of wineries grow their own grapes and therefore the grapes do not change hands until the wine has been bottled. Wineries that produce their own grapes have greater control over the quality of grapes produced, and this removes the issue of moral hazard. If wineries grow their own grapes, price will not be used to the detriment of the grape quality during a specific season, and therefore the price will only be used as a parameter to indicate quality once the grapes have been processed, and turn into wine (Lock *et al*, 2019).

The second link in the wine value chain is the impact of price on quality, and this arises when the wine has been produced and is ready to be sold to the public. Logically the price of wine, as with other goods, will have a strong and positive association with its quality, as perceived by consumers (Bombrun & Sumner, 2003). Wine is an extremely differentiated product, due to the wide range of wine products, which are all slightly different. Consumers are often overwhelmed by the extensive range of different wines available to them, and frequently use price, brand, region, grape variety, labelling, awards, and word of mouth and expert opinions as ways to choose a wine they should purchase (Lockshin & Corsi, 2012). Consumer behavioural patterns shift on an ongoing basis, which means that the factors that make wine sell one year might not have the same effect in the following year. The price will always be a contributing factor to whether or not consumers purchase a specific bottle of wine.

In 1986, an economics professor by the name of Orley Ashenfelter, began publishing a series of newsletters which were titled Liquid Assets -The International Guide to Fine Wines. The focus of these articles was to assess the vintage quality of wines from various regions, as well as provide a quantitative analysis of the fine wine market. A few years later Ashenfelter released the first version of the "Bordeaux equation", which was an econometric model that could be used to predict auction prices of wine by using the wine's age, as well as the weather that occurred in the year in which the grapes were grown. The model proved relatively accurate in predicting the prices of wines over the next couple of years (Storchmann, 2012).

The price of wine is often referred to as an indicator of quality, however this is not entirely true. It does not take cogniscance of the fact that everyone has a different preference - some people do not like wine and so even an expensive wine will not be enjoyed by them. The price of a bottle of wine also has much to do with certain marketing attributes such as brand, region, grape variety, labelling, and awards (Lockshin & Corsi, 2012). A wine from a well-known brand will often fetch a higher price than a wine from a smaller, less well known farm, however that does not mean that a wine from a small farm is inferior in terms of quality, to the well-known brand (Danaher *et al*, 2003).

A fundamental question which needs to be unpacked is, what is the economic value of a wine grape? This seems straight forward as this should be reflected by the price, however this leads to another question which is, what makes up the price of the grapes? The price of wine grapes sold to a wine producer is determined by the parties involved in the transaction. They are responsible for negotiating as well as agreeing on a price per ton for the grapes. The price which is agreed upon is influenced by the production costs, in addition to market factors such as the economic environment, competition, quality, service, uniqueness as well as supply and demand for the product. The quality as well as the supply of wine grapes are key aspects which are considered throughout this thesis (Tomsik *et al*, 2016; Alturria & Solsona, 2015).

The Stellenbosch wine region is synonymous with wine quality. The economic valuation of Stellenbosch Cabernet sauvignon wine grape is a nuanced concept which needs to be explored. A wine economics journal article published in 2019 by Corsi and Ashenfelter, mentioned that "Although quality is a multi-facet and slippery concept, it has a very sound economic counterpart, since it is reflected in wine prices". This being said it is important to remember that there are many factors that influence the quality of the final product, these include weather conditions during the growing and harvesting period, crucial elements which impact the quality of the grape produced. In certain instances, it has been argued that data can provide a realistic prediction of the long-term price of wine. For example, Ashenfelter, Ashmore, and Lalonde (1995), found that better vintages occurred when the preceding winter was wet, spring and summer temperatures were high, and summer was dry. Furthermore, there is an intrinsic uncertainty regarding the quality of the final product, which is impacted by this wide array of factors. The quality will only be determined once the product is tasted and even then, it still remains subjective (Corsi and Ashenfelter, 2019).

There have been numerous attempts by a number of people to create models to show how climatical factors influence the quality of the final product, that can be derived from the price of the end product. One of the

most common models used to predict these outcomes is through the use of a hedonic pricing framework (Hargrave, 2019). which can be seen in the works of Bombrun and Sumner (2003); Combris, Lecocq, and Visser (1997); Costanigro, McCluskey, and Mittelhammer (2005); Nerlove (1995); Oczkowski (1994); and Schamel and Anderson (2003). A hedonic pricing model is used to estimate the extent to which each factor affects the price of a product. The estimation of these different hedonic price frameworks is to show that the market price is in essence determined by the objective characteristics found in the wine. The estimation of these frameworks shows that quality, unlike the market price, is essentially determined by the sensory characteristics. These hedonic frameworks have also been used to determine the optimization of grape type selection for a specific location. They also provide an indication of the value that a specific vineyard should produce in the future. Another important aspect of the hedonic frameworks is to assess how much value consumers implicitly place on aspects such as sensory characteristics and labelling, as this helps assess how important wine quality really is (Ashenfelter, 2019).

The relation of grape quality to the weather is provided for several well-known viticultural areas, including Burgundy, Bordeaux, Rioja, and the Piedmont. (Combris *et al*, 1997). In 2008 Sanja Lutzeyer wrote an article with the aim to estimates a hedonic price function for Stellenbosch wines to determine the association between market value and different characteristics of these wines. The article presents an econometric valuation tool to establish the relationship between wine price and value for three South African red wines cultivars (Merlot, Cabernet Sauvignon and Shiraz) from a consumer's perspective. Value is modelled using unsighted and sighted scores from local wine platters guide which is measured in stars as quality measurement (Lutzeyer, 2008). The 'intrinsic values' of different wines are calculated to see which wines have maximum value relative in comparison to their price. The article found that only limited numbers of red wine varieties and sub-districts of production significantly influence the average price of Stellenbosch red wines. The article went on to unpack the relationship between consumers knowledge of a wines characteristic and the influence it can have on the wine prices from the demand side of the market. It was also noted that the average consumer does not have access to information about the chemical and climatic characteristics and is generally not aware of the sensory characteristics of a wine at the time of purchase (Lutzeyer, 2008).

As mentioned earlier, wine is a product with highly differentiated quality characteristics. It is very complicated to define an objective overall measure for wine quality. For example, a wide range of the sensory quality indicators are highly subjective. These include factors such as color and intensity, aroma and sweetness, as well as acidity, mouthfeel and body (Schamel, 2000). Supplementary indicators which can also be used to indicate quality are features such as labelling, bottle design, or the reputation of wine producers and growing regions from where the grapes are produced. This may improve or hinder the sale of a particular wine. It has been observed that the prices for two similar bottles of wine may differ significantly despite having similar sensory quality characteristics. For instance, Guenter Schamel, who is a Professor at the Faculty of Economics & Management at the Free University of Bozen-Bolzano, used an example of a wine from Napa Valley, California. This wine typically sells at a higher price than a wine of comparable quality from elsewhere. He went on to argue that it was clear to see that consumers do not have sufficient information about sensory wine

quality attributes. Therefore, consumers tend to buy particular wines based on their reputation. It was further argued that consumers may be prepared to pay a higher price for a reputable wine from a well-known origin. (Schamel, 2000).

Wine grapes fall under the category of an intermediatory product and not as a final product. Intermediate goods such as wine grapes can be defined as products that are used in the production process to make other goods, which are ultimately sold to consumers (Kenton, 2019). It has been argued that the value of an intermediate product can be derived from the value of the final product. This can be calculated using either the market price or the cost of production if a product is not being sold but rather transformed into something else, such as wine. Another way in which economists calculate the value of such products is through the value-added approach, in order to guarantee that they are not counted twice—once when purchased, and once when the final good is sold (Kenton, 2019). An example used to unpack the value-added approach in layman's terms can be illustrated by a farmer who grows wheat. The farmer sells his wheat to a miller for R100, and the farmer earns R100 in value. The miller grinds the wheat to make flour which can be seen as a secondary intermediate good. The miller sells the flour to a baker for R200 and creates R100 in value (R200 sale - R100 purchase = R100). The baker uses the flour to make breads, which are the final products and sold directly to the consumer. The baker sells the breads for R300, adding another R100 in value (R300 - R200 = R100). The final price at which the breads are sold is equal to the value that is added at each stage in the production process (R100 + R100 + R100). Therefore, the value added is equal to R300 (Kenton, 2019). Similar to this example a wine grape grower could sell his grapes to a wine producer at a set price and the wine producer will transform the grapes into wine. During this process, the wine maker will add additional value and therefore, in an ideal world, the wine should be sold for more than the value of the grapes.

The willingness to pay as well as the willingness to accept are another two techniques which can be used to estimate the true value of wine grapes as well as the true value of the wine. Willingness to pay is the highest price a customer will agree to pay, while willingness to accept is the lowest possible price the seller can afford accept (Campbell, 2020). There are many factors that affect the willingness to pay and willingness to accept, such as the state of the economy, how trendy/seasonal is the product currently and the rareness of a product, as well as the quality of a product (Campbell, 2020).

The willingness to pay and the willingness to accept for wine grapes, in particular Cabernet Sauvignon, is highly influenced by the geographic location where the grapes are grown and the reputation of the area. There remains a strong belief that the best wines can only be produced in particular areas due to the favourable physiological attributes. The knowledge of growing grapes and making wine, derives from a deep intimate appreciation of the interaction of these attributes that have been developed over a long period of time (Lock *et al*, 2019).

Geographic location has an important role to play when it comes to the economic valuation of the grapes. For example, Burgundy in France is known as the home of Pinot Noir and Chardonnay grapes, due to perfectly suited terroir for these cultivars (Carew & Florkowski, 2010). Another example which showcases the

importance of location is the region of Stellenbosch, which is known to produce some of the best Cabernet Sauvignon grapes/wines in South Africa. Cabernet Sauvignon is also known to be the king of Stellenbosch wines. This is due to unique terroir of the region (Bredahl, 2020). Wine grape buyers will pay a premium to get grapes from such regions due to the inherent reputation these regions have for producing quality grapes of those specific cultivars. Wine grape buyers will often buy these grape due to their so-called better quality. Grapes from these regions have extra clout as wines produced from these specific cultivars sell for higher prices due to the reputation of producing better quality wines. This is one of the reasons why the concept of wine of origin classification is important. This is particularly true for wine producers as it illustrates what region the grapes come from and can have a direct impact on the value of the end product. (Lock *et al*, 2019).

Consumers' willingness to pay also varies according to their social and demographic background, as well as their knowledge of the product (Skuras & Vakrou, 2002). An important question that needs to be dissected is how particular quality characteristics affect consumer willingness to pay for wine? It has been argued by Günter Schamel that the implicit price can be derived for quality attributes which include variety, sensory quality ratings, as well as individual and collective reputation indicators as well as information on region of origin (Schamel, 2000). The value of wine quality to consumers and how quality indicators influence their willingness to pay for premium wine is conundrum that needs to be reviewed. When consumers fully depend on sensory quality ratings, their willingness to pay should not be affected by other quality indicators such as experts' opinions or ratings of the wine or the label of the wine for which implicit prices are then zero. However, when collective and individual indicators provide additional information about wine quality to the consumer, these implicit prices will not be zero (Schamel, 2000).

Another mechanism which can be used to evaluate the economic valuation of wine grapes is through the production costs incurred in order to produce them. This is also tied in with the willingness to accept as these two concepts can be derived from one another. Average cost of production has a direct impact on the price of products. It also needs to be mentioned that profit is the life blood of business, and without it no business can survive in a competitive market (Lacalle, 2020). In order to make a profit, the price multiplied by the quantity needs to be larger than the production costs, as profit is equal to revenue minus costs. Therefore, the average production costs will have an impact on the price that grape growers will be willing to accept. It also needs to be noted that different areas will have different average production costs.

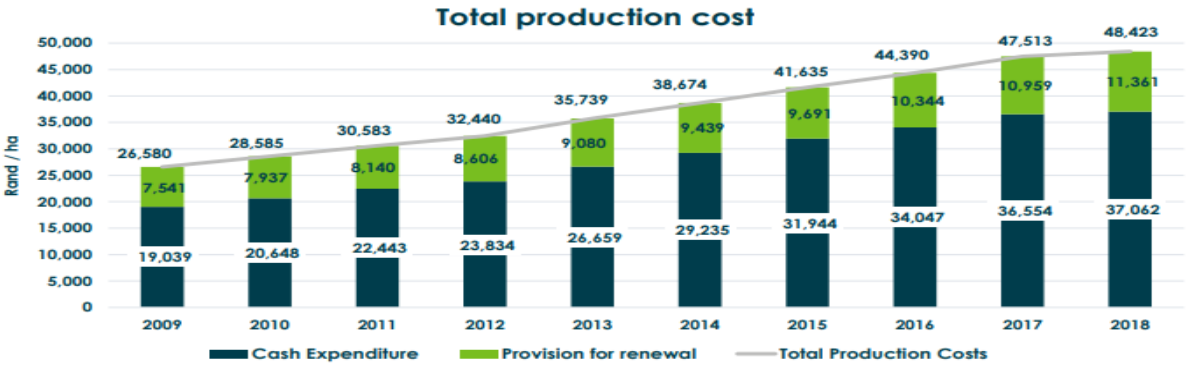
Table 2.8: production costs of wine grapes per district for the 2018 harvest

Industry average per district	Klein Karoo	Robert-son	Worces-ter	Breed-ekloof	Olifants River	Orange River	Paarl	Stellenbosch	Cape South Coast	Durban-ville	Industry Average	Swart-land
COST STRUCTURE												
DIRECT COST	**5 225**	**7 725**	**7 971**	**7 484**	**4 719**	**5 479**	**5 317**	**6 473**	**7 967**	**8 084**	**6 449**	**3 800**
SEED	-	50	128	75	26	26	250	362	271	1 079	159	47
FERTILISER	2 138	2 963	3 380	2 420	1 991	2 636	1 508	1 047	1 582	1 337	2 071	1 092
ORGANIC MATERIAL	160	84	453	878	591	228	4	162	219	-	299	10
CROP PROTECTION	1 978	3 315	2 438	2 602	1 576	1 494	1 814	3 127	4 356	3 854	2 498	1 983
HERBICIDE CONTROL	508	1 138	1 059	1 024	378	719	1 352	1 450	1 262	1 398	1 088	575
REPAIR AND BINDING MATERIAL	441	175	513	486	157	375	388	324	277	416	335	92
ARBEID / LABOUR	**10 858**	**14 269**	**12 093**	**13 979**	**10 505**	**23 400**	**14 514**	**21 613**	**22 910**	**24 684**	**15 665**	**9 523**
SUPERVISION	802	1 801	2 162	3 168	2 258	3 752	2 372	4 354	3 593	673	2 794	1 011
PERMANENT LABOUR	8 941	6 970	8 928	9 218	6 814	8 723	7 817	11 900	10 798	16 899	8 778	5 281
SEASONAL LABOUR AND CONTRACT WORK	1 115	5 498	1 003	1 593	1 432	10 925	4 325	5 359	8 520	7 112	4 093	3 230
MECHANISATION	**6 502**	**8 634**	**6 692**	**6 690**	**7 743**	**8 120**	**5 740**	**7 475**	**8 707**	**9 072**	**7 218**	**4 779**
FUEL	2 971	2 543	2 632	2 223	2 856	3 199	1 895	2 505	3 308	3 914	2 478	1 671
REPAIR, PARTS AND MAINTENANCE	2 557	4 924	2 970	3 316	3 572	3 058	2 383	3 750	3 134	4 265	3 428	1 599
LICENSES AND INSURANCE	789	824	772	804	942	1 248	543	776	1 240	893	801	432
HIRED TRANSPORT	185	343	317	347	373	614	919	444	1 026	-	511	1 077
FIXED IMPROVEMENTS	**1 569**	**1 189**	**1 375**	**1 507**	**750**	**1 171**	**1 245**	**1 593**	**1 801**	**2 382**	**1 311**	**897**
REPAIRS AND MAINTENANCE	1 327	867	945	1 121	390	528	839	1 155	1 522	1 776	916	634
INSURANCE	241	323	430	386	360	643	405	438	279	605	396	263
GENERAL EXPENDITURES	**7 148**	**7 179**	**7 437**	**5 806**	**8 417**	**6 631**	**4 725**	**5 853**	**8 046**	**9 018**	**6 419**	**2 796**
ELECTRICITY	2 825	4 180	3 704	3 871	3 679	2 148	2 022	2 003	2 624	2 814	3 006	973
WATER COSTS	2 771	1 186	1 799	319	2 718	1 575	1 019	874	295	1 077	1 246	1 032
LAND-, PROPERTY- AND MUN TAXES	217	222	399	306	569	379	323	597	337	871	391	193
ADMINISTRATION	1 334	1 591	1 536	1 310	1 451	2 529	1 361	2 378	4 791	4 256	1 775	599
TOTAL CASH EXPENDITURES	**31 302**	**38 996**	**35 567**	**35 467**	**32 133**	**44 799**	**31 541**	**43 007**	**49 432**	**53 240**	**37 062**	**21 794**
PROVISION FOR RENEWAL	**12 554**	**11 629**	**11 672**	**11 598**	**12 940**	**11 177**	**10 066**	**10 759**	**13 024**	**13 051**	**11 361**	**8 506**
VINEYARDS	6 892	6 418	6 884	6 848	6 233	6 555	6 529	6 413	6 656	6 256	6 543	5 836
FIXED IMPROVEMENTS	837	947	1 126	980	1 545	1 054	858	1 265	2 024	840	1 116	515
MOVEABLE ASSETS OR PRODUCTION MEANS	4 825	4 264	3 661	3 770	5 163	3 568	2 679	3 081	4 344	5 956	3 702	2 155
TOTAL EXPENDITURES	**43 856**	**50 626**	**47 239**	**47 065**	**45 074**	**55 977**	**41 607**	**53 765**	**62 456**	**66 291**	**48 423**	**30 301**

Sourced from Vinpro, 2019

Table 2.7 which originates from the 2018 Vinpro production plan survey, illustrates the production cost of wine grapes per district for the 2018 harvest. This illustrates the industry average per district. It is clear to see that the four most expensive regions out of the twelve regions are Durbanville (R66 291), Cape South Coast (R62 456), Orange River (R55 977), Stellenbosch (R53 765). These prices will have a direct impact on the willingness to accept the price agreed upon by the different parties (Vinpro, 2019).

An interesting avenue that needs to be discussed, for the purpose of this thesis, is how production costs are affected during drought. This is due to the linkage that has been established between production costs in relation to economic valuation, as well as the linkage between economic valuation and the overall quality of the wine grapes



.

Figure 2.10: Change in the Average production costs of the south African wine industry, sourced from Vinpro, 2018.

Figure 2.10 Which originates from the 2018 Vinpro production plan survey, show the change in production costs over a ten-year period. The figure 2.10 shows the change in average total and the second graph shows the change in the direct costs. These are broken down into fertilisers, crop protection and herbicides production, and includes the costs of grape producers in the Western Cape from 2009 to 2018. In the first illustration the total production costs increase from R26,580 in 2009 to R48,423 in 2018 with an average increase per year of 6.91%. However, from 2015 to 2018 (a drought period), the average yearly increase was only 5.19% which is lower than the average increase in total production costs during this ten-year period.

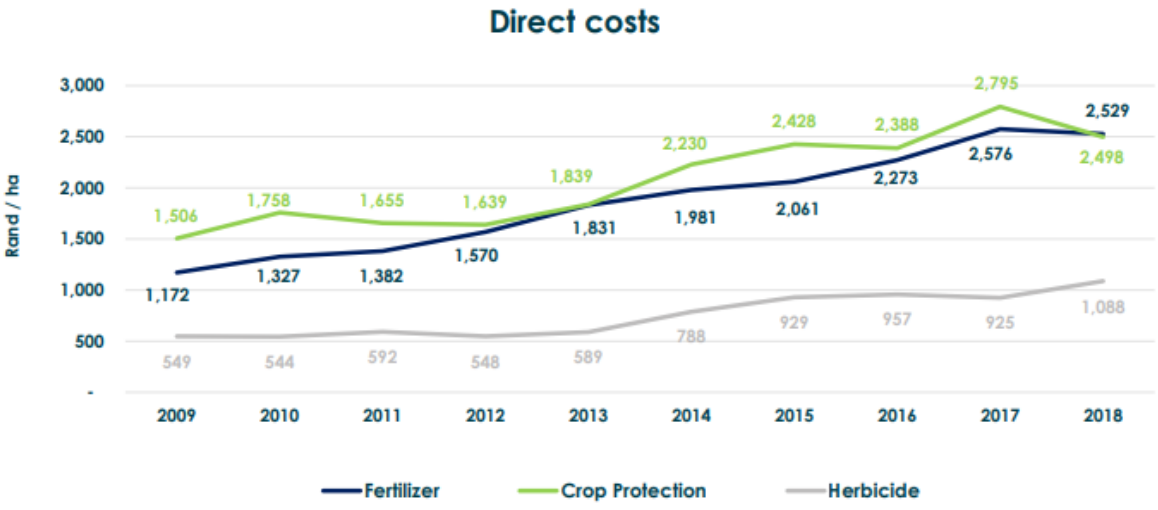


Figure 2.11: Change in the average direct cost for the South African wine industry, sourced from Vinpro, 2018.

In terms of direct cost (which is broken down into fertilisers, crop protection and herbicides) there was an average cost increase of 12.86%, 7.32% and 10.91% respectively. The average increase of these costs however during the drought years 2015-2018 were 7.60%, 1.54% and 5.71% respectively which is again than the average increase in these costs over this time period (Vinpro, 2018). It can be argued therefore that the total production costs as well as direct costs (fertilisers, crop protection and herbicides) did not suddenly accelerate

during the drought years, but actually increased at a slower pace, compared to the averages over this ten year period.

The overarching question that needs to be address is whether the price of wine is a true reflection of the quality of the product? Unfortunately, there is not a straightforward silver bullet answer to this question, due to the fact that quality is firstly subjective as well as being influenced by a large number of different aspects. These include factors such as the sensory characteristics of the wine, the cultivar, the region of origin, the bottle, the label, the marketing of the wine as well as the farm /regions reputation, to mention but a few. The matter that needs to be decided on is whether or not a wine such as the De Toren Expression Unique Book XVII which is a Cabernet Sauvignon dominant red blend, produced in Stellenbosch, is worth R3862 a bottle (Wine-Searcher, 2020). There is no right or wrong answer to this question, as it will depend on the person drinking the wine. This is why the economic valuation of wine and wine grapes will remain a lengthy debate going forward.

2.8 Viticulture Practises that influence the grape quality

When a viticulturist wants to try and improve the overall quality of the grape, they must understand each specific block of grapes, as numerous factors can influence the quality of the grapes. Each cultivar is unique, and what improves quality for one cultivar could be detrimental to another cultivar (Poni *et al*, 2018). This necessitates a viticulturist understanding the microclimate of the vineyard before they can try and improve the grape quality. Another factor that needs to be considered is the element of timing, as viticulture practices need to be conducted at the right time for the vines to produce good quality grapes. (Poni *et al*, 2018)

Certain viticultural practices will influence the grape quality. These practices include irrigation, vine spacing, crop size, and vineyard floor management. There is however no “one rule that fits all”, as each block will grow slightly differently, so certain viticulture practices could be beneficial, and others could negatively affect the grape quality. Fruit exposure to sunlight after veraison is key to get consistent ripening throughout a Cabernet Sauvignon block, and canopy manipulation is the practice that is responsible for fruit exposure to sunlight. A practice such as topping, hedging, and basal leaf removal may influence the concentration of aroma compounds in the grapes in particular, which will affect the overall quality of the grape (Reynolds, 2010).

Irrigation should be timed meticulously. If farmers can only irrigate once in a season, it should take place post-harvest. If there is enough water to irrigate twice in a season, vineyards can be irrigated during the bud burst stage as well (Balint, 2012). According to the Vititec CEO Nico Spreeth, wine grape producers, in the longer term will have to look at drought-resistant vines. These vines produce more acidity, flavour, and larger yields, but have lower water needs. In the work of Van Zyl (1984) he refers to Rutten (1977) and Freeman (1978), who both investigated the impact of soil moisture sensitivity on different cultivars, in addition to the impact on the grape quality. Their results showed that modest water stress can benefit grape quality positively; however severe water stress may have a negatively affect the grape quality, as well as the permanent vine structure. Controlling the water supply is a key component in achieving optimal grape quality. However, the optimal grape quality occurs between two extremes; one is the oversupply of water, which causes extensive vegetative growth, as well as larger yields but not the best quality. The other extreme is that of severe water

stress, which will also negatively impact quality and could end up killing the vine. Moderate water stress however can benefit the overall grape quality (Van Zyl, 1984).

Canopy management and pruning, at the right time, is another important practice that can help improve yield and quality. Larger canopies have a higher water requirement. Therefore, during a drought, it is important to keep the canopy slightly smaller, compared to non-drought periods, and to remove water shoots throughout the season. All these measures will help vines have a better yield during a drought period (Heyns, 2016). In 2010 Elman Bahar and Semih Yasasin published an article in the African Journal of Agricultural Research Vol. 5 (21). The article investigated yield and berry quality under different soil tillage, and cluster thinning treatments in Cabernet-Sauvignon. Three soil treatments and two different cluster thinning treatments were analysed to find out how it influenced the yield and berry quality. The three soil treatments were conventional tillage (CVT), minimized tillage (MIT) and conservative tillage (CST), and the two cluster thinning techniques were no cluster thinning (NTH) and 50% cluster thinning (CTH) (Bahar & Yasasin, 2010). The results regarding the change in yield showed that there was a 35% decrease in yield for the CVT with 50% cluster thinning, as compared to the CVT with no cluster thinning. Both the MIT and CST had a 37% decrease in yield when 50% cluster thinning occurred. For quality, three parameters were analysed: titratable acidity, total phenolic compounds, and total anthocyanins. The results in terms of the quality parameters indicated that the titratable acidity was higher when no cluster thinning occurred compared to when 50% cluster thinning took place, under each of the soil treatments. The result of the total phenolic compounds and total anthocyanins was not as straight forward, and are illustrated in the figure below (Bahar & Yasasin, 2010).

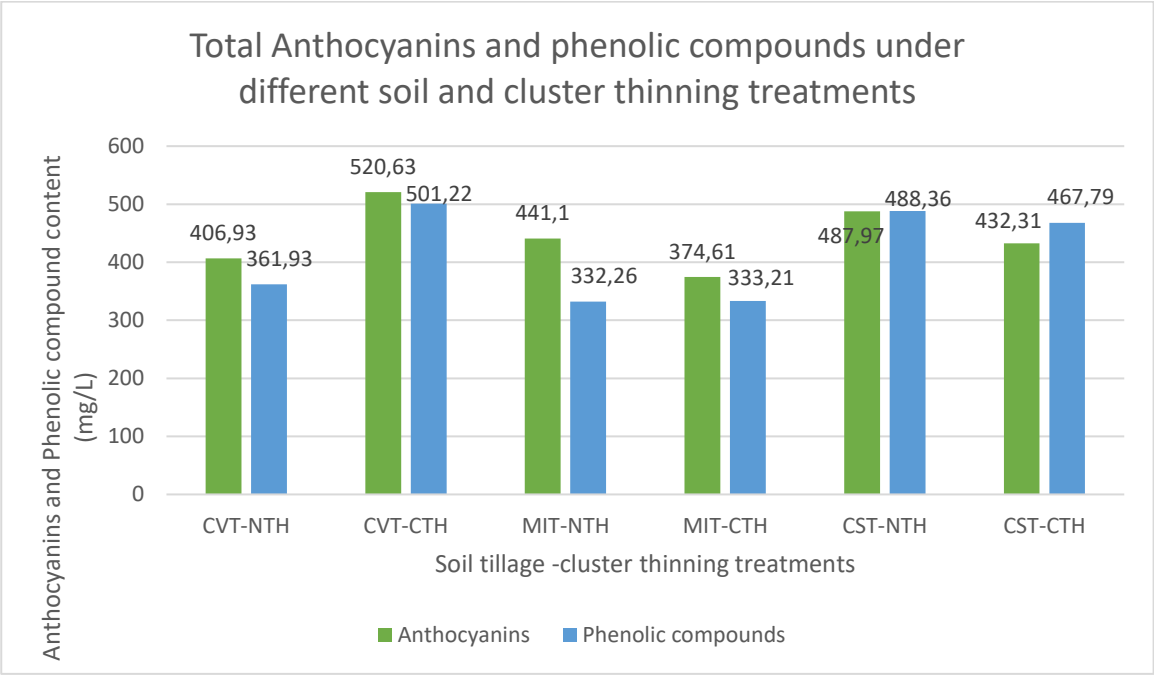


Figure 2.12: Total Anthocyanins and phenolic compounds contents under different soil and cluster thinning treatments at harvest, sourced from Bahar & Yasasin, 2010

Figure 2.12 shows that conventional tillage with 50% cluster thinning had the highest total anthocyanins and phenolic compounds of the six different treatments, whereas minimized tillage with 50% cluster thinning had the lowest total anthocyanins content. The minimized tillage with no cluster thinning had the lowest total phenolic compound content of the six treatments. This means that conventional tillage with 50% cluster thinning had the best berry quality, in terms of the three parameters. Under different terroir and viticulture practices however, this investigation could have shown different results (Bahar & Yasasin, 2010).

In 2003, Wheeler, Black and Pickering conducted a study that investigates the influence of four different vineyard floor management techniques on the grape quality of Cabernet Sauvignon in New Zealand. The study was conducted under normal growing conditions, which took place during an average rainfall year. The four methods that were used were: a permanent cover crop of chicory, a cover crop of chicory that was sprayed with herbicide before veraison, a layer of sawdust, and bare soil. The results from these four different methods were based on shoot growth, leaf size, yield, and sensory evaluation. In terms of shoot growth, both chicory treatments considerably reduced the soil water content, which resulted in a reduction in shoot growth compared to the other two methods. Leaf size was the smallest with the sawdust, followed by the permanent cover crop of chicory. There were no noteworthy differences in yield among the different treatments (Wheeler *et al*, 2005). Both chicory treatments resulted in early ripening with an increase in soluble solids and a decrease in titratable acids, in addition to increased anthocyanins, and reduced ammonia content, compared to the other two treatments. Sensory evaluation of wines produced from grapes under each treatment was conducted after four years of bottle age. The permanent cover crop showed riper fruit aroma and flavour, and had the higher overall quality score, followed by the cover crop that was sprayed with herbicide before veraison (Wheeler *et al*, 2005). Nevertheless, these results will differ under different terroirs with different climatic and soil conditions.

2.9 The impact of droughts and water availability on grape yield and quality

As mentioned above, droughts are the consequence of a natural reduction in the amount of precipitation received over an extended period, which affects the production of wine grapes. Quality and yield are the two key components of wine grape production. In a hypothetical scenario, a wine grape producer would ideally want to produce high-quality grapes at a high yield, however these two factors tend to have a negative relationship. As the yield increases the grape quality tends to decrease, as the vine's total energy and focus is being broken down into more components. This causes the negative relationship between these two key factors of production (Matthews & Nuzzo, 2007).

Drought periods put vines under water stress and cause soil water depletion; the effect of this will depend on the severity of the drought, in addition to the terroir, as well as certain viticulture and irrigation practices. As mentioned earlier, dryland vineyards do not receive any form of irrigation, and therefore the impact of droughts can be directly observed. During drought periods, vineyards are faced with increasing water stress, which can be linked to the decrease in soil water.

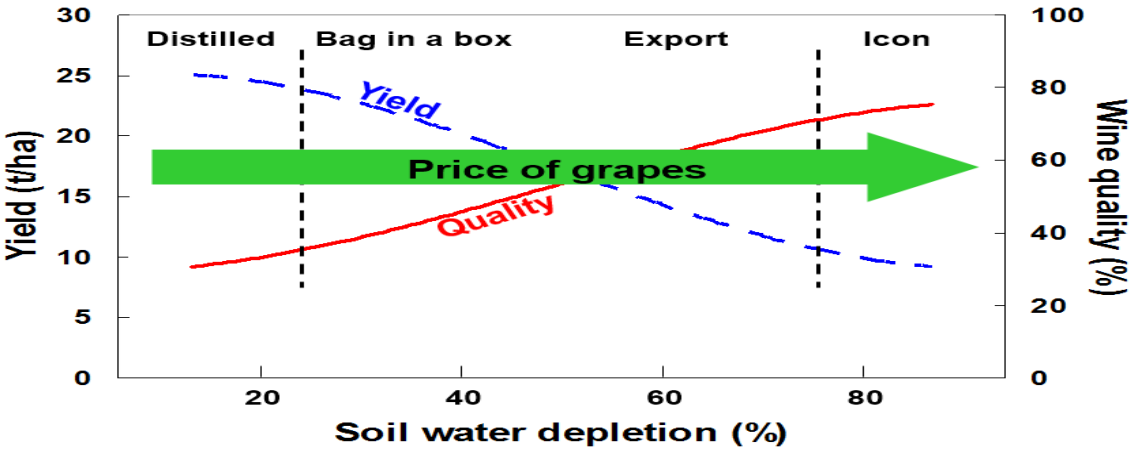


Figure 2.13: Yield and wine quality at different soil water measurements, sourced from Myburgh, 2009

Figure 2.13 is a graphical representation of how soil water depletion affects grape yield as, well as wine quality and the overall price of the wine being produced. The illustration shows that as soil water depletion increases, so wine quality increases which is coupled with the increase in price which is depicted by the green arrow moving from left to right, which correlates with the words as the top of the figure. For example distilled wine also be referred to as bulk wine is on the top left hand side of the figure this is the lowest price category of wine typically costing less than R60 and on the right hand side there is icon wine which is a the most expensive category of wine which includes wine at a price of over R1500 (Slater, 2018). It needs to be noted however that as the soil water deficit percentage increase so the grape yield decrease at the same time. The limitation of this diagram is that it does not state during which period of the growing stage the soil water depletion was measured. Nevertheless, it indicates how water stress influences the relationship between grape yield, wine quality as well as price.

According to Myburgh (2006) irrigation schemes for a wide variety of climatic conditions, soil types, and vineyard practices to optimise grape quality in addition to wine quality, has not been well documented. Water deficits can influence grape composition in more than one way. Vine water stress due to the lack of water, can retard sugar accumulation, especially when grapevines yield high crop loads. Water stress has also been known to decrease total titratable acidity, which can harm the overall wine quality. Severe water stress can also delay colour development in red-coloured grapes such as Cabernet Sauvignon (Myburgh 2006). Mild water stress can cause certain quality parameters in wine grapes, such as the size of the berries, in addition to causing anthocyanins and phenolic compounds to increase; this would lead to what is considered better grape quality.

Vineyards under irrigation tend not to feel the full impact of a drought, as long as there is water for irrigation to occur. Numerous field trials have been conducted by ARC Infruitec-Nietvoorbij, as well as other authors, to determine the effects of different irrigation schemes on wine quality, as well as how irrigation can benefit wine grape production during drought periods (Myburgh, 2006; Ferreyra et al, 2002; Kaiser et al, 2001; Vallone et al, 2004; Azevedo-Opazo et al, 2001; Salon et al, 2001). A study conducted by Myburgh (2006) showed how the timing of irrigation can influence the wine colour, berry aroma, and overall wine quality –

this study was conducted on a block of Merlot planted on Richter 99 rootstock in Wellington. The table below illustrates the finding of the study.

Table 2.9: The influence of drip irrigation on Merlot planted on Richter 99 rootstock in Wellington

Timing of irrigation applied before harvest	Wine colour (%)		Berry aroma (%)		Overall wine quality (%)	
Season	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
Control (non-Irrigation)	80	84	45	56	55	62
Pea size, veraison	85	80	68	50	66	61
Peas size, mid-December veraison, and end of January	75	75	47	33	47	51
Partial root zone drying	79	65	57	39	59	46

Sources from Myburgh, 2006

In table 2.7 it is clear to see that the control test, as well as irrigation at pea size and veraison, achieved the best results. Wine colour percentage was the best with irrigation at both pea size and veraison, whereas in 2004/05 the wine colour percentage was better in the control test with no irrigation. When analysing wine quality during 2003/04, the double irrigation schedule at pea size and veraison obtained the best wine quality, whereas in 2004/05 season the best wine quality was obtained with the control test. Another test was conducted by Myburgh (2006), which investigated how the irrigation schedule impacts vegetative growth, yield, and wine quality percentage.

Table 2.10: An Irrigation cycle and its impact on Colombar grape yield and wine quality

Irrigation cycle (days)	Plant available water depletion (%)	Cane mass (t/ha)	Yield (t/ha)	Wine quality (%)
11	30	4.3	36.0	47
16	50	3.9	33.5	47
45	75	3.0	28.7	53

Source Adapted from Myburgh, 2006

Table 2.8 illustrates that by adjusting irrigation cycles, the plant water availability is affected. This impacts the vegetative growth of the grape yield as well as the overall wine quality. If irrigation occurs every eleven days, then the plant available water depletion percentage will be 30% and the vegetative growth will have a cane mass of 4.3 tons per hectares which is the largest weight for cane mass. Cane mass is a measure of vine vigour obtained by weighing the canes removed from a vine at winter pruning (Sawis. 2020). Yield with an 11-day irrigation cycle is also at its largest with a yield of 36 tons per hectare, which is above the average yield for Colombar, and the wine quality was 47%. With a 45-day irrigation cycle the plant available water depletion percentage is at its largest (75%). However, the cane mass is at its smallest with a weight of three tons per hectare, Yield is also at its lowest at 28.7 tons per hectare and finally, the wine quality is at its highest of 53%. This shows that there is an inverse association between grape yield and wine quality, with regard to plant available water. As the plant available water depletion percentage increases, the wine quality increases and the grape yield decreases (Myburgh, 2006).

In 2001, an article was published in the International Symposium on Irrigation and Water Relations in Grapevine and Fruit Trees, by Cesar Azevedo-Opazo, Samuel Ortega-Farías, and Yerko Moreno. They tested six different water applications on Cabernet Sauvignon to measure vine evapotranspiration (ETvine). The first three water applications took place between fruit set and veraison and the last three water applications took place after veraison. The tests were as follows:

Post fruit set

- T1; irrigation = 100% of the ETvine
- T2; irrigation = 70% of the ETvine
- T3; irrigation = 40% of the ETvine

Post veraison

- T4; irrigation = 100% of the ETvine
- T5; irrigation = 70% of the ETvine
- T6; irrigation = 40% of the ETvine

Table 2.11: The effect of altered water applications during post fruit set and post veraison on Cabernet Sauvignon vines in the Pencahue Valley in the 2000/2001 season

Treatment	Yield (ton/ha)	The ratio of skin to pulp	Soluble solids (°B)	pH	Titratable Acidity (g/L)	Total Phenols (mg/L)	Total anthocyanins (mg/L)
T1; 100% ETvine	13.7	4.7	24.8	3.69	3.89	2732	368
T2; 70% ETvine	9.0	4.8	25.3	3.71	3.61	2755	400
T3; 40% ETvine	8.2	5.0	25.6	3.73	3.73	3045	439
T4; 100% ETvine	11.0	4.7	25.6	3.77	4.01	2782	367
T5; 70% ETvine	10.2	4.8	25.4	3.72	3.72	2873	405
T6; 40% ETvine	9.6	4.8	24.7	3.66	3.65	2876	435

Source Adapted from Azevedo-Opazo *et al*, 2001

The results of these different treatments show similar results to the test conducted by Myburgh (2006). As the level of irrigation decreases, the yield of Cabernet Sauvignon grapes decrease, however, the decrease in irrigation levels also caused certain of the quality parameters to improve. Both total phenols and anthocyanins increased as the amount of irrigation decreased. The ratio of skin to pulp increased slightly as the irrigation amount decreased. When analysing the decrease in irrigation at post fruit set (T1-T3,) the soluble solids and pH increased slightly, however, a decrease in irrigation after veraison (T4-T6) caused the soluble solids and pH to decrease, and titratable acids tended to decrease. With a decrease in irrigation, the results from these parameters indicated that as the irrigation volume decreases from 100% ETvine to 40% ETvine the yield decreases, however, the majority of the quality parameters improve which signified an improvement in overall grape quality (Azevedo-Opazo et al, 2001).

The increase in grape quality influenced by a moderate drought period, as well as a slight reduction in plant water availability, will cause the price of wine grapes to increase if they are being sold to wineries. Many other factors also influence the price however, so it is difficult to quantify the influence that the drought will have on the quality of the grapes against the price (Landon & Smith, 1998). Severe droughts can have detrimental effects on the quality of grapes, as when a vine faces water stress, it results in reduced canopy development and an insufficient leaf area to support fruit development and maturation, thus decreasing the grape quality (Camps & Ramos, 2012).

Revenue is made up of two main components: price and quantity. According to Pienaar and Bonaire (2018), the decline in yield will have a larger impact than the increase in price for grapes during a drought period. Therefore, revenue is expected to decrease (Pioneer & Bonaire, 2018). Farmers growing wine grapes during a drought period need to adapt their practices to avoid lower yield, but at the same time produce higher-quality grapes. In the short-term, farmers need to carefully manage water loss and soil moisture. This management technique is implemented by using cover crops mulch or plastic, which helps the soil to retain moisture (Ingles *et al*, 2005).

After reviewing the literature around the quality and quantity of grapes, and how they are affected during a drought period, it is clear to see that a drought will have an impact on both the quality and quantity of grape production. The impact each drought period has on the quality and quantity will vary, as many other variables do not stay constant.

A drought will however decrease wine-grape yields and possibly increase wine grape quality; this will depend on the severity of the drought, as the grapes will have increases in total soluble solids, total anthocyanins, and phenolic concentrations. There will however be a reduction in titratable acid levels, which people often use to judge a grape's quality (Mirás-Avalos & Intrigliolo, 2017; Azevedo-Opazo et al, 2001).

In terms of revenue, the decrease in yield will have a larger impact on revenue when compared to the increase in quality, as the price of grapes will not increase enough to counterbalance the decline in yield (Pienaar & Boonzaaier, 2018). There are certain factors that farmers can change to optimize the quality and quantity of grapes produced during a drought, such as the management of water loss, soil moisture, and irrigation schedules, as well as replacement of certain older vines. These vines can be replaced with other drought-resistant cultivars, and they can use rootstocks that are also drought resistant. By changing these factors, the reduction in revenue can be reduced.

Chapter Three: Methodology

3.1 Introduction

Following on the literature review in Chapter two, Chapter three discusses the methods used in this study to measure the quality, as well as the yield of Cabernet Sauvignon grapes in the Stellenbosch region, to establish how drought periods impact both these factors. For this study, a concurrent triangulation, mixed-method research design is used, as both qualitative and quantitative research is combined to form case studies. This chapter will begin by discussing the rationale behind the study area, followed by the research methods used, and these can be broken down into a series of subsections. Firstly, it will begin by discussing the ethical measures taken in the collection of this data. Secondly, it will discuss the data collection procedures used for this study, as well as a measure used to ensure the validity and reliability of the data and finally, it will discuss the different methods used to process and analyse the data for this study (Le Roux, 2012; Bak, 2004).

3.2 Study area

The area of study for this research is the Stellenbosch region, found in the Western Cape of South Africa. The area of Stellenbosch is one of the most well-known wine regions in South Africa, claiming more than half of the local and international awards presented annually to South African wines (Lutzeyer, 2008). In 1971, Stellenbosch became the first wine region in South Africa to establish a wine route as an organized network of wineries, that break up the area of Stellenbosch into five main sub-routes. The five sub-routes are Bottelary Hills, Greater Simonsberg, Helderberg, Stellenbosch Valley, and Stellenbosch Berg. These sub-routes are home to more than 150 wineries. To give the reader a better visual idea as well as to explain the layout of these different sub-routes found in Stellenbosch, a map of the Stellenbosch wine route can be found in Figure 3.1. The figure below is a graphical representation of the different wineries that fall under the different sub-routes.

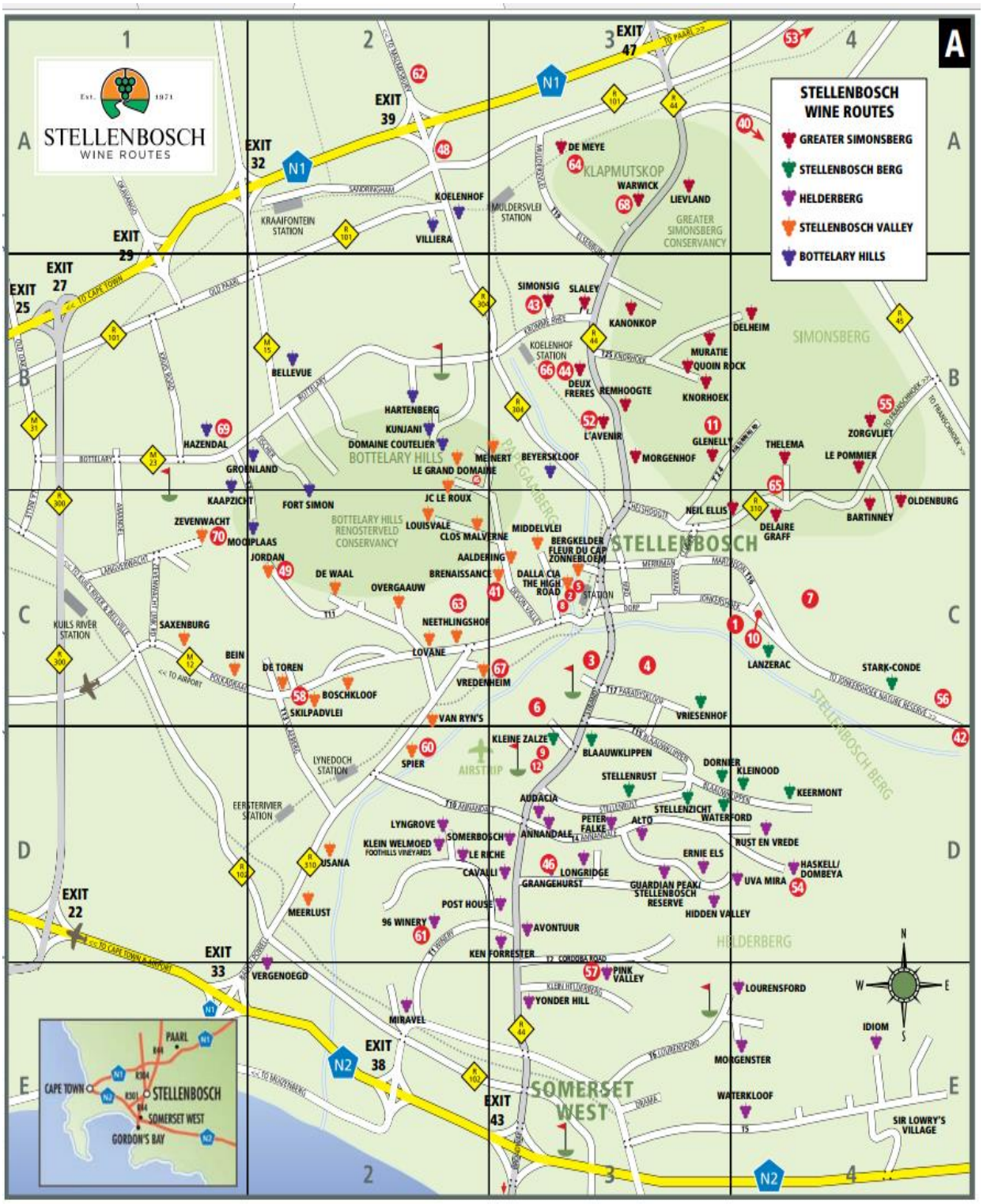


Figure 3.1: The Stellenbosch wine routes, sourced from the Stellenbosch Wine Route, 2020.

3.3 Research methods

A key component of this research study is the research design, as it explains to the reader how the research study was constructed, as well as how the data was collected and analysed. Research designs are conceived around strategies, processes, and techniques that are utilized to collect data or evidence for analysis, to reveal

new information or create a better understanding of a topic (Kothari, 2004). For this study, the geographical focus is the Stellenbosch region, which is located in the Western Cape of South Africa, and the topic of discussion is focused on droughts and the implications that they have on the quality as well as the yield of Cabernet Sauvignon wine and the wine produced from these grapes. This research can be classified as such, as it investigates how droughts have impacted grape quality, as well as yield, and discusses methods which can be implemented to minimize the negative impacts of droughts, in terms of quality and yield. This research can be recognized as being applied research, as it aims to find possible solutions and new ideas concerning the implications of drought conditions on Cabernet Sauvignon grapes, that will be of potential benefit to the wine industry in the future. It can also be identified as fundamental research, as it aims to improve scientific theories and understanding around this topic (Kothari, 2004). This research can also contain both quantitative and qualitative research and therefore can be classified as having a mixed methods research design (Bryman, 2006; Creswell & Clark, 2011).

Tashakkori and Creswell define mixed methods research as "research in which the investigator collects and analyses data, integrates the findings and draws inferences using both qualitative and quantitative approaches or methods in a single study". They then go on to refer to the works of Greene, who defined mixed method research as being "multiple ways of seeing which opens up a wide range of applications beyond the use of just a single research method". Both of these definitions make it clear that mixed methods combines both qualitative and quantitative approaches to formulate a unique research method, which has several advantages as well as challenges that need to be unpacked, before this method can be fully understood (Tashakkori, & Creswell, 2007).

The use of mixed methods for this study has numerous advantages, compared to other research designs. By combining both qualitative and quantitative research, many of the weaknesses of these individual methods are eliminated. An example of this can be illustrated by the fact that the voices and opinions of participants are often not expressed through quantitative research, however, qualitative research can make up for this weakness. Quantitative research is nevertheless better suited than qualitative research for unpacking number trends, so by combining both these methods, a variety of these weaknesses are mitigated. Using mixed methods enables a researcher to use a larger range of tools to collect the data, without being constrained as to whether the data is considered as being qualitative or quantitative (Creswell & Clark, 2011). Mixed methods can also assist in increase findings reliability and credibility, through the triangulation of both qualitative and quantitative, to improve the accuracy of the conclusion. The mixed methods research design has certain shortfalls and has been criticised, which researchers need to be aware of. Many of these criticisms spring from the belief that quantitative and qualitative research methods cannot be blended in a single study, as they have such different ontological and epistemological origins. It has also been said that mixed methods research is inclined to be complex as well as timely in nature (Doyle *et al*, 2009). Nonetheless, if the mixed methods research is done correctly, the advantages outweigh the disadvantages, and there has been a wide consensus that mixing different types of methods can strengthen a study. Mixed methods research has been coined as the third

research paradigm, as it allows qualitative and quantitative research to be combined into a single paper (Creswell & Clark, 2011).

The mixed-method design which is used for this study is that of concurrent triangulation. This is considered as the most frequently used of the six major mixed methods designs. The concurrent triangulation design used in this study interprets both qualitative and quantitative data at the same time, which permits the data to be studied from different angles, as well as giving equal weight to the qualitative and the quantitative data. The qualitative data helps provide information for the one side of this research study as well as to cross validate the findings of the quantitative data. This triangulation approach uses the qualitative and quantitative data in synergy, to get the most out of the data. The qualitative data is used to assess how Cabernet Sauvignon grape quality has been affected by droughts, which cannot be evaluated using quantitative data. At the same time, the quantitative data will be used to answer questions on how the yield has been affected by droughts (Boeije, 2009; Creswell *et al*, 2008). The figure below is a graphical illustration of the concurrent triangulation layout, which has be used in this research.

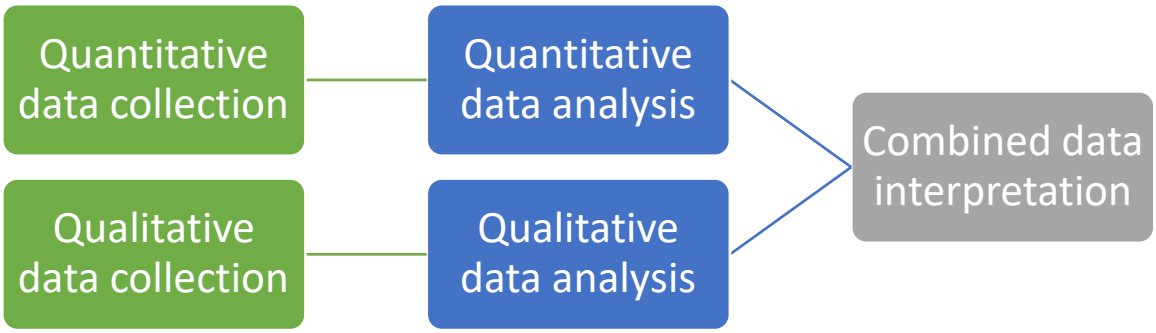


Figure 3.2: The concurrent triangulation layout, source adapted from Creswell *et al*, 2008

Figure 3.2 shows that concurrent triangulation mixed methods research firstly collect the quantitative and qualitative data concurrently, and analyses it simultaneously to interpret the data, and come to an appropriate conclusion. The qualitative and quantitative data also has similar weighting, as neither type is prioritized (Creswell *et al*, 2008). This method strives to attain results through corroboration, convergence, and correspondence, from both qualitative and quantitative information (Creswell & Clark, 2011).

This study seeks to investigate how droughts have impacted both quality and yield of Cabernet Sauvignon wine grapes in the Stellenbosch regions. As quality is a subjective term, comparative groundwork is needed to come to a consensus around what quality is. Due to nature of this study, case studies are one of the methods

used, as they are an appropriate method for this research question. They give in-depth coverage, as well as a detailed analysis of the wineries, and they allow wineries to be compared to one another to find common trends. This has been used to show how droughts have impacted both the quality and yield of Cabernet Sauvignon wine grapes.

3.3.1 Data collection sample and methods

The data collection for this research was broken down into two parts; the first part entails the collection of the primary data, which has been collected through a self-administrative questionnaire and semi-structured interviews with viticulturists, winemakers, harvest interns, and farm managers on different wineries located throughout the Stellenbosch region. Questionnaires were sent to wineries from the five sub-routes of Stellenbosch region. These sub-routes are Bottelary Hills, Greater Simonsberg, Helderberg, Stellenbosch Berg, and the Stellenbosch Valley. Snowball sampling was used to select the wineries for the data collection, however these wineries needed to fit certain criteria, and were selected on the following basis. Firstly, that they grew their own grapes, even if they bought or sold a portion of these grapes to other wineries. Secondly, they had to use some of these grapes to produce wine on the farm, and finally, they had at least one block of Cabernet Sauvignon which they produced wine from, as this is the particular cultivar of interest for this research. A snowball sampling method was used to select a few wineries from each sub-route. The data is not therefore representative of the entire winery universe in South Africa, and inferences consequently cannot be made about the entire wine industry. The questionnaire was also sent to employees of different companies within the wine industry, and these employees would prefer to remain anonymous for the duration of this research therefore, their gender race and identification will not be revealed. This questionnaire was initially sent out via email, to over one hundred different wineries within the different sub-routes of Stellenbosch, and thirteen wineries responded. Some of the respondents answered the questionnaire via email, however a few of the respondents wanted to meet in person to answer the questionnaire, rather than do so over email. This was to get a clearer insight of the study, and to get clarity on some of the questions. The rest of the respondents either did not want to participate in the study or no longer fitted the criteria for the study. The questionnaire was therefore either filled in or sent back via email, or it was completed in person. This allowed two-way communication to take place between the researcher and the respondent, which created a platform for further questions to be asked, based on the respondents' answers. This meant that respondents could elaborate on their answers. Although the sample size is relatively small, the in-depth answers elicited quantitative data.

The questionnaires for the respondents from the wineries comprises of 27 questions, that can be broken down into three main sections; not all sections were applicable to each respondent. The first part of the questionnaire is an overview section, that comprises of general questions, to try and get an historical as well as a current picture of the winery. This section of the questionnaire comprises of thirteen questions. The overview section also tries to establish how droughts have affected that particular winery, in addition to how the respondent measures quality in wine grapes. The second section of this questionnaire is made up of scenario questions, posed to get an understanding of how the respondent would react to future drought scenarios, as well as what viticultural practices would be implemented or adjusted during drought periods. The final section of the

questionnaire focuses more directly on the impact that droughts have on the yield, quality and price of Cabernet Sauvignon grapes, as well as the wine produced from these grapes. Certain of the questions use a five-point Likert Scale, which as mentioned earlier is one of the best ways to measure people's opinions and perceptions and is an easy scale to construct information to collect qualitative data (Zikmund *et al*, 2013). These questionnaires were used to collect data on a micro-scale and were analysed to see how the drought has affected these different wineries. By combining the data from the different questionnaires as if they were puzzle pieces, a broader picture is created which describes how droughts have affected the Stellenbosch region as a whole.

3.3.2 The rationale behind the data collection

The context behind this data collection is an important area that needs to be unpacked, in order for the reader to get a clear idea as to why the research was conducted in this particular manner. The first component that needs to be unpacked, is why Stellenbosch was chosen as the geographical location of interest of this research. The reason behind why the Stellenbosch region was chosen for this study is relatively straight-forward - Stellenbosch is known by many as one of the most famous wine-producing regions in South Africa. It is also home to over 150 wineries and has the oldest as well as the largest wine route in South Africa (Ferreira & Muller, 2013). The second component will look at why Cabernet Sauvignon was selected as the cultivar of interest for this study. The answer to this question diverges from the previous answer, as Cabernet Sauvignon is the most abundantly planted cultivar in the Stellenbosch region, out of both red and white wine cultivars. In the 2018, South African wine industry annual report, Cabernet Sauvignon was the most planted cultivar (40%) as well as being the cultivar with the largest number of hectares under cultivation with approximately 32% of the total number of hectares under wine grape production being in the Stellenbosch region (SAWIS. 2018).

The rationale behind why the individual wineries were included, as well as why the particular sampling method was used, is also an important factor that needs to be considered when seeking to understand this research. Due to an expected low respondent rate, as many wineries as possible were approached, to make sure sufficient data was generated from these questionnaires. The data collection methods used for this research were selected by the type of data that would be collected. The primary data was collected through the use of a questionnaire, in order to obtain both qualitative and quantitative data simultaneously. The change in yields contained quantitative data, whereas the change in quality comprised of qualitative data. A questionnaire also allowed a large amount of primary data to be collected in a relatively short space of time, with relatively low costs attached.

3.3.3 Ethical measures

Due to the nature of the research, as well as the fact that the primary data will be collected through a self-administrated questionnaire and semi-structured personal interviews, ethical measures need to be administered. With most forms of qualitative data collection, several important ethical concerns should be addressed before the data collection process can commence. For this research, the issues of confidentiality, anonymity, and informed consent from the participant, as well as the larger organization, needed to be considered, as any information that they give could impact their reputation. Before any data for this study could be collected, ethical clearance from the Research Ethics Committee (REC) of Stellenbosch University needed to be

obtained. For this study, the ethical clearance process started in March 2019, in terms of which certain documents needed to be uploaded. These documents included a research proposal for the study, the research questionnaire, as well as a proposed consent form and institutional permission letter for the respondents and the gatekeepers respectively. These documents were to inform them about the study, as well as get their consent to be included in the study and can be found in an annexure at the end of the study. After the documents had been uploaded, a wide range of questions needed to be answered, before the application could be submitted. The first draft of the ethical clearance application was submitted in May 2019, and several weeks later the application was returned, with certain issues that need to be corrected. Once the correction had been made it was resubmitted to the REC, and approval was received on the 1st of August 2019.

The ethical clearance approval letter from the REC states that data collection could not take place before the consent form and the institutional permission letter had been signed, as that meant that both the respondent and wineries were aware of the study and confirmed their participation. Several of the respondents, as well as a few of the wineries, required that their names were omitted from the study, as they felt certain information could taint their reputation. To keep results uniform in nature, respondents' names were removed, and just their title was used. The wineries names were replaced with different letters of the alphabet, which were allocated according to their sub-routes in which they are located.

3.3.4 Measures to mitigate sampling errors

With all types of data collection, errors occur in the form of sampling errors and non-sampling errors, and it is important to try to mitigate these biases as far as possible. For primary data collection, the questionnaire was sent to as many wineries that fitted the criteria as possible, from the five different sub-routes of Stellenbosch, in order to reduce the sampling errors. Another way in which sampling error was reduced was by splitting the wineries from Stellenbosch into the different sub-routes; responses were obtained from each of the five sub-routes, which meant the data was not skewed to one particular sub-region of Stellenbosch. The low response rate to the questionnaires however needs to be recognized as a limitation to this research. To try and reduce non-sampling errors the questionnaire used simple language, to make sure the respondent was able to understand the questions. Another way in which non-sampling errors were mitigated, was by using more than one method of data collection. The self-administered questionnaire allowed respondents to answer the questions directly and in their own time, whereas the semi-structured personal interviews recorded the data, in order to improve the accuracy of the data, and was transcribed at a later stage.

3.3.5 Measures to ensure validity and reliability

Particular measures were taken to ensure that the data collected was both reliable and valid. Reliability is improved if sampling bias and sampling errors are minimized (Laxton, 2004). The first measure which was used to increase the reliability of the data collected, was to try and collect information from as many different wineries across the Stellenbosch region as possible, to get a reliable indication of how droughts have impacted the different wineries in terms of both quality and quantity. It was also critical to collect data from each of the different sub-routes in Stellenbosch, to gain a full picture, rather than one that is skewed to a particular sub-route. This was achieved by breaking Stellenbosch down into its sub-routes, and it created multiple viewpoints

from which the study can be seen, so that a more accurate view of the subject is obtained (Gibbs, 2018). Another way to ensure that the data gathered from the questionnaires was valid and reliable, was through the wording of the questions. Questions were worded in such a way as to make them as straight forward and as objective as possible (Laxton, 2004).

The data collected through the self-administered questionnaire was via email and was a direct typed response to the questions posed to the respondent, which has a number of advantages and disadvantages. The self-administrated questionnaire allowed the respondent the freedom to answer the questions in their own time, without being influenced by the interviewer. It also allowed the respondent to answer the question in as many or as few words as they like, without being asked to elaborate on certain things. This can lead to the issue should respondents not answer the question as comprehensively as required. The prevalent issue that arises with the use of a self-administered questionnaire was a low respondent rate, which meant follow up emails were required to remind respondents that the questionnaire needs to be sent back when completed.

The rest of the data was collected in person, through a semi-structured personal interview with the respondents, and the questions from the questionnaire were read to respondents. On arrival the respondents were asked if they would mind being recorded, so that the information could be transcribed at a later stage, and the majority of the respondents accepted. The major advantage of recording the interview, is that it allowed the interviewer to focus on the interview rather than writing notes. It also meant that all the answers to the questions are stored and could be transcribed at a later stage. Another benefit that arises through the use of semi-structured interviews, is that it made the respondents' job easier, as they could just answer verbally rather than type their answers, and so were more willing to elaborate on certain questions, as well as give context to their answers

Using a combination of these two methods to collect the data for this research lead to an increase in the respondent rate, as well as making the respondent more at ease with the questionnaire. Each of the methods had certain shortfalls but by using more than one method to collect the data, the shortfalls were covered, which improved the credibility as well as the significance of the data. A reliable synopsis of the situation was gained, which allows for a more integrated conclusion to be attained.

3.3.6 Data processing and analysis

The data was collected and transcribed from the self-administered questionnaires and semi-structured interviews and was compiled into an extended word document that was grouped according to the location of the winery. Due to the nature of the data, only certain analytical methods could be used to unpack and break down the data into smaller components, in order for the data to be interpreted. A combination of both thematic and narrative analysis was used for the qualitative data, as they were the most appropriate analysis methods for this type of data; they are both flexible and straightforward methods to use to unpack data (Hsieh & Shannon, 2005). By using a combination of thematic and narrative analysis, a diverse yet equally substantial and consequential interpretations were allowed, focusing on different elements within the data (Allen, 2017). The quantitative data is derived from the change in yield caused by the drought and used the percentage change as a tool to interpret this data. The analysis began by grouping the data into the five different routes in which

the winery is located, before the data was analysed. The data for each of the wineries was colour-coded, according to themes and subthemes. This method uses an inductive approach by using specific observations to identify patterns within the answers, which were then grouped to develop tentative theories. An inductive approach means letting the concepts and theories emerge from the data, which can then be used to create a narrative for the different sub-routes (Hsieh & Shannon, 2005). Once the themes had been colour-coded, narratives were created and included information from each of the different wineries, which were grouped according to the sub-routes in which the wineries are located. These narratives formed case studies for the different sub-routes, as the narratives give in-depth coverage, as well as detailed analysis of the wineries from these sub-routes, regarding how droughts have impacted the grape quality and quantity of Cabernet Sauvignon in particular. The analysis will also use an idiographic approach, in the sense that it will investigate each winery as an individual, and as a unique case even though there will be certain factors that different wineries share, such as similar soil type, irrigation schedules or even the age of the vines. Each winery will be unique and have certain aspects that are not the same as the next winery in the area. This approach not only stresses the uniqueness of each winery, but also the holistic nature of social reality (Gibbs, 2018).

Interpretivism was used in conjunction with the two analysis tools, to fully unpack and analyse the data collected. Interpretivism is used to gain a deeper understanding of the particular phenomenon and its complexity in its unique context, instead of trying to generalize the base of understanding for the whole population (Creswell, 2007; Pham, 2018). The knowledge acquired through the discipline of interpretivism is socially constructed rather than objectively determined, and it also embraces more personal and pliable research structures, that are able to capture meanings in human interaction (Carson *et al*, 2001; Edirisingha, 2012).

Chapter Four: Findings

4.1 Introduction

The previous chapter unpacked the methods as well as the rationale behind certain characteristics chosen for this study. As previously mentioned, a total of thirteen respondents from wineries agreed to take part in this study. The respondents from the wineries were viticulturalists, winemakers and farm managers from the different wineries in the Stellenbosch region. The rest of the respondents were employees of different companies within the wine industry. The data collected from these respondents will be used to get an overview of the Stellenbosch region, rather than site-specific answers. This chapter will be used in collaboration with the previous chapters, to review the findings from the primary data collection. For this chapter, the author will identify the major findings from the data collected. The data will be analysed descriptively to provide insights on the impact that droughts have had on different wineries. Due to the fact that the data from each of the wineries is unique and site-specific, generalizations will need to be avoided.

This chapter will be broken down into five subsections. It will start by discussing the general background, as well as giving some context to these wineries. It will then analyse what viticultural practices can be implemented during drought periods, to minimize the negative impacts of drought conditions, as well as potentially optimise Cabernet Sauvignon grapes in terms of both quality and quantity. Thirdly it will discuss how droughts affected the Cabernet Sauvignon grape. Fourthly it will analyse how the respondents view grape quality, in particular Cabernet Sauvignon grapes, and what parameters they use to measure quality. Finally, it will discuss whether the quality parameters used to measure quality have increased or decreased during drought periods in order to critique whether the Decrease in quantity of the Cabernet Sauvignon grapes has been counterbalanced by the increase in quality of wine grapes during droughts or which one has been impacted the most.

4.2 Background and context to the respondents at the various wineries

Background and contextual understanding of the individual respondents and their positions, as well as information about the winery is important, as it allows the reader a better understanding of the specific contexts from which the questions were answered, as they are site-specific. Each winery will have been impacted differently by drought, however it can be seen that certain patterns occurred, based on certain respondents' answers. These show that even though each winery is unique, there are certain practices that occur at multiple wineries, as they are based on industry norms and practices. The background and context of the respondents at the various wineries will be sorted according to the route which they are situated on; this will take place in alphabetical order starting with the Bottelary Hills route and end with the Stellenbosch valley route. The background and context are linked to information provided by the respondent therefore specific profiles will be more detailed than others. However, each profile will give a basic background and context to each of the respondents as well as that of the various wineries. There were another three respondents that worked for various companies within the wine industry, however they were not linked to one specific winery. Their answers were broader and aimed at giving an overview of the Stellenbosch region compared to other wine

grape production and winemaking regions, rather than on a farm level. These respondents will be referred to as respondents fourteen, fifteen and sixteen.

4.2.1 The Bottelary Hills route

There are two respondents from different wineries from the Bottelary Hills route. In order to maintain their anonymity for this study, the respondents will be referred to as:

- Respondent one from winery A
- Respondent two from winery B

Respondent one is a viticulturist at winery A and has been working there for the last three years, under the guidance of the farm manager. Winery A grows grapes at three different sites on the Bottelary Hills route. These three sites together are 77 hectares in size, however only 50 hectares are currently planted with vines. 30 hectares are planted with Pinotage (20 hectares of Trellised and 10 hectares of Bush vine), 15 hectares are planted with Cabernet Sauvignon, 10 hectares are planted with Merlot and five hectares are planted with Cinsault. No white grape cultivars are grown on the farm, as winery A focuses on red wine production. The first site comprises of two blocks of Cabernet Sauvignon which were planted in 2000 and 2010 respectively. The 10-year-old block is situated on a slightly flatter slope, at a slightly higher altitude compared to the older block. The soil in these blocks comprises of Hutton and Kroonstad soils with areas of “koffie klip” on the surface. The second site is two km away from the first site and has one block of Cabernet Sauvignon vines which are 10-year-old. These vines are planted on the edge of a wetland and the soil is sandier than the first site. These vines are planted on mounds to help with drainage during the wetter months. Both these sites are fitted with drip irrigation, however the vines receive no supplementary irrigation unless there is reduced rainfall during a particular season.

Respondent two is one of the directors of the winery and has worked at the winery for over 25 years. The respondent is a qualified Cape Wine Master and is responsible for the wine production at the winery. Winery B is situated on the Bottelary Hill route and is approximately 180 hectares in size. 85 hectares of the vines are red wine cultivars (Merlot | Cabernet Sauvignon | Pinotage |Shiraz |Pinot Noir |Gamay Noir |Carignan) and 95 hectares are white wine cultivars (Sauvignon Blanc | Chenin Blanc |Riesling). There is one large block of Cabernet Sauvignon which is 30 years old. The winery is committed to preserving the environment and has been rewarded with membership to the Biodiversity of Wine Initiative. One of the aims of the winery is to ensure the quality of their grapes, and to do this they limit yields to a conservative 8 tons per hectare. Drip irrigation has been installed in all the vineyards.

4.2.2 The Greater Simonsberg route

There are four respondents from different wineries from the Greater Simonsberg route. To keep their anonymity for this study, the respondents will be referred to as:

- Respondent three from winery C
- Respondent four from winery D

- Respondent five from winery E
- Respondent six from winery F

Respondent three is the Viticulturist as well as the Estate Manager for winery C. The respondent has worked at the farm for nine years. Winery C is on the Greater Simonsberg route and has a total of 50 hectares of vines. 25 of them are red wine cultivars (Cabernet Franc, Cabernet Sauvignon, Merlot Shiraz, and Malbec and Petit Verdot). The average age of the Cabernet Sauvignon premium block is 19 years old and is well established, whereas the younger blocks, such as block sixteen and seventeen, are seven years old. The other 25 hectares are comprised of white wine cultivars (Sauvignon Blanc, Chenin Blanc, and Chardonnay). The winery is situated on the crest of the Helshoogte Mountain Pass and has deep rich soils which suit a wide range of wine grape cultivars. At winery C, the more premium wines are made from grapes grown on the estate, as the viticulturist can monitor their growth during the season and can grow them to their specifications. Irrigation for example will apply only when needed to increase quality, rather than tonnage, as they focus on producing quality grapes which can be turned into high-quality wines.

Respondent four is the viticulturist at winery D and has worked at the winery for the last four years. Winery D is situated on the Greater Simonsberg route. The winery comprises of two sites which are three kilometres apart. The first site is 36 hectares, planted exclusively with white varieties (Chenin Blanc, Chardonnay, Sauvignon Blanc, and Weisser Riesling). The second site has 85 hectares, planted to both red (74 hectares) and white varieties (11 hectares). The predominant red cultivars are Cabernet Sauvignon, Merlot, Pinotage, and Shiraz, while the whites include Chardonnay, Chenin Blanc, and Sauvignon Blanc. Half the vines have drip irrigation - this includes the four blocks of Cabernet Sauvignon which are planted on either Richter 110 or 101/14 rootstocks. The soil forms are Oakleaf, with a higher proportion of sand and quartz fragments. This site is better suited for red wine cultivars, as it is slightly warmer and has a slightly lower average precipitation compared to the first site. Winery D focuses on producing quality wines rather than large volumes of wines.

Respondent five from winery E is the head winemaker and has worked at the winery for several years. Winery E is a 28-hectare farm which is located on the Greater Simonsberg route, with only 17 hectares under vines. 12 hectares is Cabernet Sauvignon, which is the only red wine cultivar planted on the farm. The 12 hectares is broken up into eight different blocks. The average age of these vines is 20-year-old. The other five hectares are white wine cultivars (Sauvignon Blanc and Chardonnay). Winery E is a biodiversity champion and believes that truly great wine begins in the vineyard, and a great vineyard is founded in a diverse and healthy ecological environment. Most of the soil is categorized into the Hutton series and is a deep red soil that is highly weathered, very stable, and well-drained, with a good water-holding capacity and is rich in nutrients. All the vines are fitted with drip irrigation, the source of which is the Theewaterskloof Dam.

Respondent six is the farm manager, as well as a viticulturist at winery F. Respondent six has been with the winery for the past four years. Winery F is situated on the Greater Simonsberg route and is 530m above sea level, with mainly south-facing slopes. The high altitude and the rich deep red soils are ideal for premium quality wine grape production. Winery F believes grape quality is the single most important factor in serious

winemaking. Winery F is 157 hectares in size and grows both red and white wine grape cultivars. The white wine cultivars include Sauvignon Blanc, Chardonnay, Riesling and Muscadel, and the red wine cultivars include Merlot, Shiraz and Cabernet Sauvignon. Winery F consider themselves as a leader in the production of Cabernet Sauvignon.

4.2.3 The Helderberg route

There are two respondents from two different wineries from the Helderberg route. To keep their anonymity for this study, the respondents will be referred to as:

- Respondent seven from winery G
- Respondent eight from winery H

Respondent seven is the farm manager of winery G and has worked at the winery for the last five years. The winery is situated on the Helderberg route and is a relatively small winery, however its exact size was not disclosed. This winery is certified as being organic and biodynamic, and produces its grapes accordingly, by not using any herbicides, pesticides, or chemical sprays in the vineyards. The farm is also home to cattle that meander about the farm and provide manure that is later used as compost on the farm. There are also ducks which help control insects and other pests in the vineyards. Winery G grows both white (twelve hectares) and red grape cultivars (nine hectares); these cultivars include white wine grape cultivars of Chardonnay, Verdelho, and Chenin Blanc, as well as red grape cultivars of Merlot, Cabernet Sauvignon Cabernet Franc, Petit Verdot, and Pinotage. There is one large Cabernet Sauvignon block which is now 10years old, and is under drip irrigation, as it is one of the last blocks to be harvested.

Respondent eight is the head winemaker at winery H and has worked at the winery for the last nine years. Winery H is situated on the Helderberg route and is situated in the heart of what is known as the golden triangle. This area is famous for producing some of the best Cabernet Sauvignon wines in South Africa. This is due to the unique terroir, which is influenced by the cooling ocean breezes, which help the vines produce small berries with optimum ripeness, the concentration of fruit flavour, great colour and smooth tannins found in the Cabernet Sauvignon grapes. Winery H is 51 hectares in size and comprises of 17 hectares of white grape cultivars and 34 hectares for the red grape cultivars. Winery H grows three white grape cultivars, namely Chardonnay, Sauvignon Blanc, and Viognier, as well as seven red cultivars, namely Cabernet Franc, Cabernet Sauvignon, Merlot, Pinot Noir, Pinotage, Shiraz, and Petit Verdot. Winery H has seven blocks of Cabernet Sauvignon, and this is the flagship cultivar at the winery. All seven of these blocks are fitted with irrigation, however the method of irrigation was not mentioned.

4.2.4 The Stellenbosch Berg route

There are two respondents from different wineries on the Helderberg route. To maintain their anonymity for this study, the respondents will be referred to as:

- Respondent nine from winery I
- Respondent ten from winery J
- Respondent eleven from winery K

Respondent nine is the farm manager and viticulturist at winery I, however they did not disclose how long they have been working at the winery. Winery I is situated on the Stellenbosch Berg route and is predominantly a red wine focused farm, with 52 hectares of red grape cultivars and no white wine cultivars on the farm. They do however buy some white wine grapes in from other farms. There are six different Cabernet Sauvignon blocks on the farm and the vines in these blocks are between 12 and 19 years old. They are planted predominantly on decomposed granite soils. These blocks of Cabernet Sauvignon comprise of high-density planting of vines, and Winery I is one of the first farms in South Africa to do so. Vines are planted at 5 555 vines per hectare, to have the vines closer to each other, which causes more inter-vine competition. The object of this is to produce smaller berries with more concentrated flavours. The vines are grown in a bio- sensible way and herbicide, as well as insecticides, are kept to a minimum.

Respondent Ten is currently working as the farm manager at winery J, after being promoted from head viticulturist a few years back, and has been working on the farm for the last 12 years. Winery J is located on the Stellenbosch Berg route. The farm is 50 hectares in size, which is made up of 27 hectares of red grape cultivars such as Pinotage, Cabernet Sauvignon, Shiraz, Merlot, and Petit Verdot and 17 hectares of a variety of different white wine cultivars. The farm's main focus is on Pinotage, as more than half of the red grape vines are Pinotage. There is however one five hectare block of Cabernet Sauvignon, which is 26 years old, and is the second oldest block on the farm. The sad reality is that this block is starting to struggle from leaf roll virus, and will most likely need to be replaced in the next couple of years.

Respondent eleven is the winemaker at winery K and has worked there for the last ten years under the guidance of the cellar master. Winery K is situated on the Stellenbosch berg route with 24 hectares of vineyards. Eight hectares are red wine cultivars which include Grenache, Malbec, Pinot Noir, Pinotage, Shiraz, Cabernet Sauvignon, and Mourvèdre. The other six hectares are planted with Chardonnay vines. The respondent mentioned that the Cabernet Sauvignon vines were planted in 2006, however there was no mention of how many blocks of Cabernet Sauvignon were currently on the farm. All the vines are fitted with drip irrigation, however during drier years, water is allocated to the younger vines. The Cabernet Sauvignon vines therefore did not receive any additional irrigation between 2015 and 2019.

4.2.5 The Stellenbosch Valley route

There are two respondents from different wineries from the Stellenbosch valley route. To keep their anonymity for this study, the respondents will be referred to as:

- Respondent twelve from winery L
- Respondent thirteen from winery M

Respondent twelve is one of the winemakers at winery L, and has worked there for the last four years, subsequent to becoming one of the youngest Cape Wine Masters in South Africa. The winery is situated on the Stellenbosch Valley route and is 16 hectares in size. It is recognized as a boutique winery and focuses on quality rather than tonnage, and concentrates on red grape cultivars and is comprised of Merlot, Pinotage, Cabernet Sauvignon, Cabernet Franc, Petit Verdot and a small vineyard of Semillon, which is the only white

wine cultivar on the farm. There is a total of six hectares of Cabernet Sauvignon vines planted on the farm, and the vines have an average age of 12 years. The winery does buys in extra white wine grapes from the Elgin region. The vineyards are all dryland vineyards with no form of irrigation.

Respondent thirteen is an assistant winemaker at winery M and has worked there for the last five years. The winery is situated on the Stellenbosch Valley route. Unfortunately, the size of the farm was not disclosed. However, it was mentioned that both red and white wine cultivars on the farm, including Chardonnay and Sauvignon Blanc white grape cultivars and Cabernet Sauvignon, Gamay, Malbec, Merlot, Petit Verdot, Pinotage and Shiraz red wine cultivars. on the farm the two most common soil types are and Oakleaf and Tukulu, both derived from ancient granite that has decomposed and are categorised as being well-drained and fertile, with high clay content and good water retention. There is also a block of Cabernet Sauvignon planted on Glen Rosa soil, which is derived from shale. This soil is slightly less fertile than the Oakleaf and Tukulu, and tends to produce smaller vines, lower yields, and highly concentrated fruit. Farm management makes use of water stress strategies to induce the vines to produce grapes with concentrated flavour. Soil moisture levels are tracked with the use of computer monitored probes, and irrigation is supplied as deemed optimal.

4.3 Viticultural practices that minimize the negative impacts of droughts on Cabernet Sauvignon vines

After evaluating the answers from the various respondents, it is clear to see that there are certain viticultural practices and techniques that have either already been utilized or are likely to be implemented during future droughts. These practices and techniques were aimed at reducing severe water stress to vines during droughts. Certain of these practices and techniques were mentioned in greater detail than others. Nevertheless, each one had a role to play by firstly helping the vine to survive the drought and secondly to restrict yield fluctuations, allowing the vines to focus their energy on grape production. The practices and techniques that the respondents spoke about were irrigation, fertilisation, mulching, cover crops, and canopy management, and a couple of others which will be discussed in further detail.

Irrigation is the first viticultural practice that will be discussed in this section, as it is often regarded as the saving grace in drier years. According to Vinpro, 88% of wine grape producers in Stellenbosch have installed some form of irrigation, whereas other regions such as Durbanville and the Swartland only have 59% and 45% of their vines under irrigation (Vinpro. 2019). Winery L was the only farm to have vines growing under dryland conditions i.e. without any form of irrigation. Nonetheless having vines under irrigation is one thing, but in order to be effective, there needs to be water available to irrigate. Respondents 9, 10 and 11 mentioned that even though their vines were fitted with irrigation, there were certain years where there was little to no water to apply to the vines. Respondent Ten went on to say that they changed their irrigation application, and only supported their younger blocks and irrigated as late in the season as possible, especially after harvest, to support and build-up the vine's reserves for the following years. Respondents 1,3 and 6 mentioned that supplementary irrigation is only given to vines in the drier years when there is lower than average rainfall, as it helps the vine buffer the stressful effects of a specific growing season. They also mentioned that the most important time for

irrigation would be post-harvest, therefore it is important to manage irrigation, to make sure there is enough water for the post-harvest irrigation.

Monitoring soil moisture levels during the drier years is critical for the vine's survival as extensive periods of water stress will cause a vine to eventually die. Respondents 7 and 13 mentioned that soil moisture probes have been installed in blocks across the farms, which has allowed them to track soil moisture levels, and irrigation supply schedules have been adjusted accordingly. Other measures that can be implemented to help monitor vines water stress, are soil moisture potential and the rate of leaf water transpiration. This will allow the vine to be irrigated only specifically when necessary. An example of this is when vines need more water during certain phenolic growth periods (i.e. during flowering) as it is important to make sure the vine is not stressed out during this period, as this will result in a poor fruit set. At post veraison, the vine needs to focus on ripening the grapes and not on vegetative growth, so a lack of water is beneficial at this stage. It is therefore important to collect data, to see how much stress the vine is under, so that water can be applied according to the vines' needs.

One of the advantages of irrigation for farms that have access to water during drier years, is that they can carefully regulate the vines' water intake and supply. Only the optimal amount of water is supplied to the vine for grape production, however there is a very fine line between the vine having enough water and a vine having too little water. The latter would cause the vine to shut down, so it can therefore be argued that it would be better to move away from dryland farming, as these vines will be affected most severely during droughts. The installation of soil moisture probes can also be beneficial, as this will allow irrigation schedules to be adapted to the vines' needs during drought periods.

Fertilisation is the next practise which many of the respondents said needs to be adjusted during drought periods. One view expressed by certain of the respondents, is that less chemical fertiliser would be needed, as it is important to restrict vegetative growth during drier years. Curbing growth allows the vines to use their energy on producing the best grapes possible. It has also been argued that extensive vegetative growth can also decrease yield, so it is essential to make sure there is a clear balance. Another opinion that was expressed was that fewer chemical fertilisers, herbicides, and pesticides should be used, as they contain salts that dry out the soil even further. An alternative to chemical fertilisers would be the use of animal manure, compost, or any other organic fertiliser as these improve soil water retention, rather than drying the soil out further.

Cover crops and mulching are two practices that all the respondents referred to as being important steps that can be implemented to reduce the overall stress caused by the drought. Cover crops have numerous uses in both average rainfall years and even more so in drought periods. The most common reasons that cover crops are used is to control weeds in the vineyards, to assist with nitrogen-fixing, loosen the soil to improve infiltration as well as to increase the soil water retention, thereby increasing the moisture in the soil, which can be vital during drought periods. Cover crops also have some secondary benefits, such as increasing the organic matter on the soil surface and acting as a form of mulch. Respondents three, seven and nine said that if drought periods became more frequent, they would advise using a mixture of permanent cover crops instead of annual

cover crops. This means the soil's surface does not need to be disturbed continuously, as that could cause the soil to dry out even further. Mulching also has several benefits, and can occur in many different forms, such as straw, woodchips, or even flattened cover crops. The four main benefits of mulching are firstly, that it reduces evaporation, which means it improves soil moisture retention. Secondly, it improves infiltration and thirdly it reduces as well as regulates the soil temperature. Lastly, mulching is used to reduce the reflection of heat onto the grapes, by changing the colour of the topsoil and making it lighter in colour. This reduces the soil temperature and the UV reflecting onto the canopy, which can cause sunburn to the grapes.

Mulching has many benefits, however it does come at a cost. Both respondents one and five mentioned that mulching was introduced during the most recent drought in various blocks, to try and improve water retention and regulate the soil temperature. They did mention however that it came at a price. Respondent one said that winery A bought 600 bags of straw at R20 a bag, which worked out to R12 000. This only covered one block of Cabernet Sauvignon vines; the actual size of the block was not disclosed. Respondent five mentioned that winery E had spent roughly R6 000 on mulch in 2017, which was used on vines planted on the steepest slopes, to try improving infiltration. Both respondents said that even though the mulch was expensive, the benefits outweighed the costs, as it meant fewer vines died from the drought in the blocks that received mulch. It needs to be noted that there are costs involved in mulching, and that this option might not be financially viable and therefore it needs to be carefully considered.

Respondent three mentioned how vines thrive when faced with slight water-stressed conditions, however there is a cut-off point where too much water stress causes the vines to shut down. This is why cover crops and mulching can be so beneficial during drier periods, as it will improve water retention and also decrease the soil temperatures, both of which generally increase with the lack of water in the soil. Cover crops also help keep the soil loose, which is needed to increase water infiltration into the soil. Therefore, the uses of both cover crops and mulching can help vines handle the drought conditions and can be the difference between the vines thriving and the vines dying.

Soil infiltration and soil water retention are two key concepts and are affected by numerous factors that include the soil makeup and gradient of the slopes. As an example, the steeper the gradient of the slope, the lower the infiltration, as well as the higher the clay content the better the soil water retention capacity will be (Fox *et al*, 1997; Romero *et al*, 1999). Vines planted on soil with better water retention and higher infiltration rates tend to suffer less during droughts, compared to vines planted on soils with low infiltration rates and water retention. This can be illustrated through the example given by respondent five who said, “Blocks four and five are both Cabernet Sauvignon blocks which are situated on a very steep slope, and experienced the largest decrease in terms of both the grape quality and quantity during the drought. This is because the soil and steep slopes have caused low infiltration rates, and moisture tends to run off down the slope rather than getting soaked into the soil. During the drought these vines were put under extreme stress and this caused several vines to die”. The higher the clay content the better the soil water retention capacity will be. This was expressed by eleven out of the thirteen respondents, who said that vines planted on soils with a higher clay content would experience a smaller decline in yield during a drought compared to soils with less clay content. By way of example,

respondent one said that “during the drought, the vines in the rockier soil had a slightly lower yield than the soils with a higher clay content”. It can therefore be argued that soils containing a higher percentage of clay tend to have a smaller decline in yield during drought periods, as the soil has a better water retention capability and can be better during droughts in this regard. It can also be argued that vines on steeper slopes will have lower infiltration rates, which could cause them to experience a larger decline in yield during droughts.

Respondent thirteen mentioned how in 2017 and 2018, a thin layer of Kaolin was sprayed onto a couple of blocks of Cabernets Sauvignon vines; this was after neighbouring farms had seen an improvement in water-use efficiency of the vines by up to 18%. Kaolin is a clay-based powder that is diluted with water and turned into a liquid that can be sprayed onto the vines as a form of sun cream. The kaolin has the potential to limit leaf water loss as well as to decrease leaf temperature. The blocks of Cabernet Sauvignon that received a thin coating of the kaolin experienced a decrease in water stress. The average leaf water potential was -1.6 MPA in the blocks that received a coating of Kaolin, whereas the rest of the blocks had an average leaf water potential of -2.1MPA. The blocks that received a coating of kaolin also had fewer vines die during this period. The Kaolin powder costs around R400 per 10kg bag, which is then diluted with water and is sprayed onto the vines. The coating gets washed off easily, even with a small amount of rain, so it is important to only apply it when there is no rain predicted for a couple of weeks. It would otherwise be a waste of time and money. Respondent thirteen went on to say that although it was a costly experiment, it was worth it.

Canopy management is another technique used on the farm to help vines handle water stress. During drought periods, vegetative growth tends to be slightly reduced, however the highest quality grapes generally do not come from the vines with the most vegetative growth. This growth can have negative impacts on the grapes’ ripening process, as the sun’s rays are blocked from entering the vine's canopy and reaching certain bunches of grapes. This being said, it is vitally important to make sure summer pruning practices, such as tipping and topping continue, especially in vines that have an abundance of vegetative growth. Respondent thirteen said that without certain pruning practises vines will use up a lot of energy on vegetative growth, to the detriment of reproductive growth, and it is therefore important to limit vegetative growth during droughts. This enables the vines to establish a sense of balance between vegetative growth and reproductive growth, so that they can have enough nutrients to ripen grape bunches fully.

A few of the respondents remarked on how pruning techniques have been adapted over the years and have become even more vital during drought years. The two methods that were mentioned were Bok op as well as Simonit & Sirch. The first method which respondent one referred to as Bok op has been used during the drought to try and restrict a drop in yield, as the vines produce more bunches, even though the grapes are smaller. Tonnage does not decrease as much as when the vines were pruned using the traditional method. This pruning method is a short-term solution to the decrease in yield, as this method cannot be used for more than two consecutive years. Otherwise it can lead to misshapen vines. The second method of winter pruning that was mentioned by various respondents is called the Simonit & Sirch method, which originated in Italy. Respondent twelve stated that this method is the way of the future and can revolutionize pruning as people know it. This method is beneficial in both above-normal rainfall years, and even more so in the drier years, as it allows

pruning to happen up and away from the cordons which are known as the arms of the vine which extend from the trunk of the vine rather than down towards the cordon. The latter would otherwise obstruct sap flow over time, making it harder for the vine to feed its new growth. The two biggest benefits that occurred from using this pruning method were firstly that it led to longer lifespans for vines, which reduces production costs. Increasing the average age of vines is hugely beneficial as it means farms won't have to replace vines as often, which will reduce production costs in the long run. Secondly, it has the potential to allow the vines to produce higher quality grapes for an extended period, as the vine has an extended mature stage lifespan, which is when a vine generally produces its best quality grapes.

The planting of more drought-resistant cultivars is the last practice that will be discussed in this section. The main question that needed to be answered was whether or not Cabernet Sauvignon vines should be replaced with more drought-resistant cultivars if droughts started occurring more frequently. The respondents mentioned that there are many different drought-resistant cultivars such as Assyrtiko, Agiorgitiko, Arinarnoa, and Marselan. There are also many other earlier ripening cultivars such as Grenache Noir, Tempranillo, and Gamay, which also handle drier conditions relatively well. The majority of the respondents however remarked that Cabernet Sauvignon is a relatively hardy red wine grape cultivar and can handle water stress from a drought a lot better than cultivars such as Merlot and Shiraz. They also mentioned that the bearing cultivar (which is the part of the vine that is above the rootstock and is responsible for producing the grapes), should be selected based on market demands and since Cabernet Sauvignon is one of the most popular red wine grape cultivars at the moment, it would be highly unlikely that they would replace Cabernet Sauvignon with another cultivar. There is also a hefty cost, as well as risks involved in replacing one cultivar with another, and this also needs to be considered before a decision can be made. Planting a new drought-resistant cultivar such as Assyrtiko might be risky, as demand for the wine produced may be low due to a lack of familiarity of the cultivar, compared to Cabernet Sauvignon.

A few of the respondents drew on the notion of replacing rootstocks instead of replacing the cultivar, as there is a wide range of different rootstocks which can be selected and each one has unique characteristics. Respondent eight said for example that during drier periods, it would be beneficial to have drought-resistant rootstocks, such as Richter 110 and 196-17. These rootstocks are excellent for drought conditions, however they struggle in wetter conditions and need to be planted on the correct soil type. There are also new hybrid rootstocks, such as M4, which are being developed continually and are considered drought resistant but can also handle wet conditions. It was also clear that the impact of the drought is site-specific and therefore a decision needs to be made on a case-by case basis. It can however be concluded that in the short term, it is unlikely that Cabernet Sauvignon will be replaced with other more drought-resistant cultivars.

4.4 The impact of droughts on Cabernet Sauvignon grape yields

4.4.1 The Bottelary hills route

Winery A

In the Cabernet Sauvignon block, which is 20 years old, the yield decreased by roughly 15-20% between 2015-2019. There was an increase however in yield between the 2019 and 2020 harvest, as there was an increase in winter rainfall compared to the previous year. Vines planted on rockier soil had a slightly larger decline in yield, compared to the vines planted on soils with higher clay content. This is because the vines planted on the soils with koffie klip on the surface tended to have less vegetative growth, and also had smaller bunches. This meant the yield decreased by a larger percentage among these vines.

The 10-year-old block at the first site is situated on a slightly flatter slope, at a slightly higher altitude. This younger block was affected to a larger extent during the drought years, compared to the older block. This could be attributed to root systems that were not as well established; there was therefore a larger decrease in yield in the younger vines compared to the older vines, of roughly 25-30%. In general terms, younger vines set more fruit than they can ripen, and will have a larger yield than older vines. During drought periods however, older vines are more established, and even though they produce smaller yields than younger vines, their yields do not fluctuate as much as the yields from younger vines. At the one end of the 10-year-old block of Cabernet Sauvignon vines, there was a trial done to see if the vines could be grown with shorter trunks. These vines have their cordon much closer to the ground, compared to a normal trellised Cabernet Sauvignon vine. The shorter trunked vines present the best of both worlds, in the sense that they could be picked relatively easily, and this could even be mechanised. They tended however to do much better in terms of resistance to droughts, as the nutrients do not need to be transported as far; the bunches form closer to the ground and therefore the yield did not decrease by as much as a normal trellis system during the drought period. These vines had the smallest decline in yield across all the Cabernet Sauvignon vines.

The second site which has a block of ten-year-old Cabernet Sauvignon vines is planted on the edge of a wetland on sandy soil. The vines closest to the wetland are planted on mounds to help with drainage during the wetter months. This block did not feel the impact of the drought for the first two years, as the vines had sufficient reserves due to the proximity to the wetland. From 2017 – 2019 however, this block suffered from a large decline in yield of roughly 25%. This was said to be linked to the sandy soil on which the vines are planted, which dries out relatively quickly and does not have good water retention.

Winery B

Respondent two mentioned that there was a total decline in the yield of the vines over the period 2015 – 2019, of approximately 30%. The cultivars that experienced the largest decline in yield were rated according to a five-point Likert, scale and the worst performers were Sauvignon Blanc (5), Riesling (5), Carignan (4), Chenin Blanc (3), Shiraz (3) and Cabernet Sauvignon (3). Smaller decreases were experienced by Cabernet Franc (1), Gamay Noir (1), Pinot Noir (2) and Pinotage (2). The yields from the older vines did not decline by as much

as the younger vines, however the decline in yield is not so much due to a single year of dry weather, rather it is the accumulative effect over many years, which leads to an extensive decrease in yield.

4.4.2 The Greater Simonsberg route

Winery C

There are seven different blocks of Cabernet Sauvignon, and each of these blocks has been affected differently in terms of yield; certain blocks have seen a larger fluctuation in yield compared to others. The data for the yield fluctuations were used to create two separate line graphs, which illustrate the yield fluctuations that occurred across the seven different blocks from 2011 to 2018. To make the graph less congested, the premium blocks were grouped together, and then a second graph was developed for the rest of the blocks.

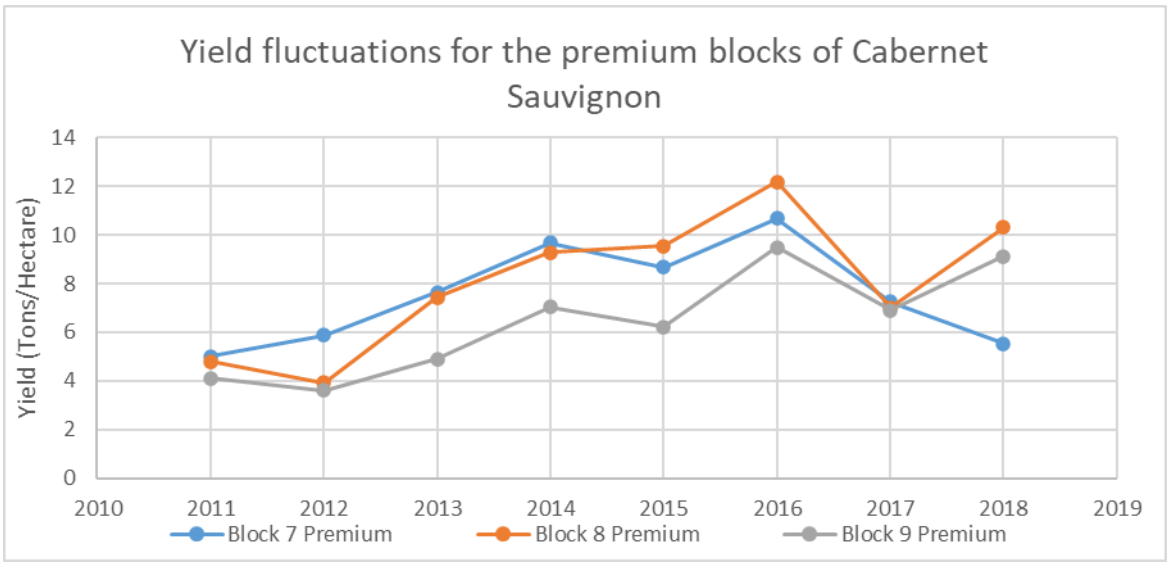


Figure 4.1: Yield fluctuations for the premium blocks of Cabernet Sauvignon from 2011-2018 at Winery C

Figure 4.1 illustrates that:

- Block seven showed an increase in its yields between 2011 and 2016, however there was a sharp decline in yield from 2016 till 2018, when yield decreased by 32.18% from 2016 - 2017 and further decreased by 23.86% from 2017 – 2018. Nevertheless, block seven showed an increasing trend in yield between 2011 and 2018.
- Block eight showed an increase in its yields between 2012 and 2016, however there was a sharp decline in yield in 2017 of 42.32%. The yield did however increase the following year, and even though there was a significant decline in yield is 2017, block eight has had an overall increase in yield between 2011 and 2018, showing in increasing trend in yield between 2011 and 2018.
- Block nine showed an increasing trend in yield between 2011 and 2018. However, during this period there were declines in yield in 2015 and 2017 of 11.65% and 27.11% respectively.

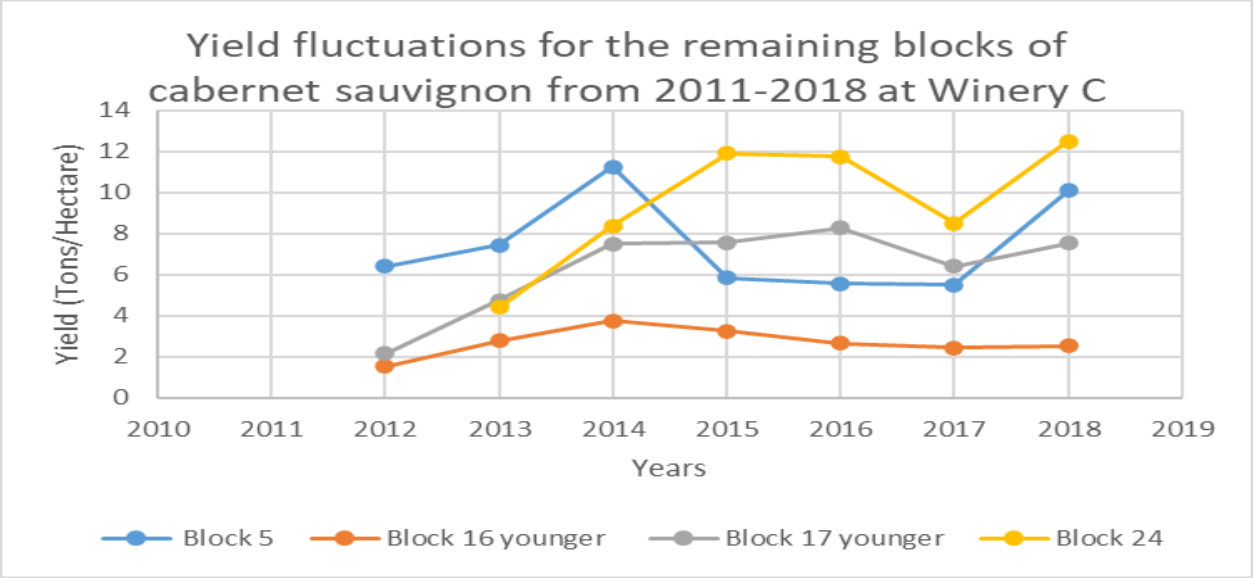


Figure 4 2: Yield fluctuations for the remaining blocks of Cabernet Sauvignon from 2011-2018 at Winery C

Figure 4.2 illustrates that.

- Block five is the only block that has not had an overall increasing yield trend between 2012 and 2018 as the trend line is flat. The yield increased from 2012 till 2014 and then declined in 2015 till 2017 and then increased again. During this period, the most noticeable decline can be seen between 2014 - 2015 of 48.13%.
- Block 16 has shown an increasing trend in yield between 2011 and 2018 however it is a very slight increase. The yield increased from 2012-2014 thereafter the yield declined from 2014 till 2018 however the yearly fluctuations in yield were relatively small compared to other blocks.
- Block 17 has shown an increasing trend in yield between 2012 and 2018. However, during this period there were declines in yield in 2017 of 22.65%. 2017 was the only year during this period where there was a decline in yield for this block.
- Block 24 showed an increasing trend in yield between 2012 and 2018, however, during this period there were declines in yield in 2016 and 2017 of 1.34% and 27.66% respectively.

Figures 4.1 and 4.2 show that the majority of the blocks experienced an overall increasing trend in yield between 2011 and 2018. It should be noted that during the period 2015 and 2017, most of the blocks experienced a decline in yield. Many of these blocks however recovered in the following year. In conclusion, it can be said that the overall tonnage of Cabernet Sauvignon did not decrease during the time graphed, with the exception of 2017. One of the reasons why the drought did not impact Winery C to a larger extent is that the farm is situated on the Helshoogte Pass ridge, which has very deep rich fertile soils, and all blocks are fitted with drip irrigation – this was used during the drought to limit grape yields fluctuations.

Winery D

Unfortunately, respondent four did not disclose any yield figures, however the respondent did mention that the yield declined significantly between 2015 and 2019. The respondent said that the two Cabernet Sauvignon

blocks, planted on 110 Richter rootstocks, experienced a smaller percentage decrease in yield compared to the other two Cabernet Sauvignon blocks, planted on 101/14 rootstock.

Winery E

Respondent five did not disclose actual yield figures, however they did mention that between 2015 and 2018, Winery E did not experience a noticeable change in the yield. This can be linked to the fact that all eight of the Cabernet Sauvignon blocks are fitted with drip irrigation and had sufficient water supply during this period to ensure that the vines did not face extensive water stress. This would have caused a significant decrease in yield. The respondent also mentioned that the reason the drought did not have an initial impact on yield, was partly due to the deep red soil on which the vines are planted. This soil has a good water-holding capacity and is rich in nutrients. Despite this, there was a significant decrease in tonnage in 2019, which was caused by numerous factors, the main one being the prolonged stress of the drought. The significant decrease in tonnage will have an economic impact for Winery E as the fixed production cost remains the same, but the decrease in tonnage will mean fewer bottles of wine can be produced.

Winery F

Respondent six did not give yield figures, however they did mention that during the most recent drought, Cabernet Sauvignon yields at Winery F have been fairly even. Although there was a slight fluctuation in the annual yields, it was within the normal range of annual yield fluctuations. The exception was the 2016 vintage, which saw a significant decrease in yield; this decrease was linked to a fire rather than to the drought. The main reason why the yields remained largely consistent during the most recent drought is because all the vines receive supplementary water via irrigation. The water used to irrigate the vines is supplied by a dam on the farm which did not go dry during the drought.

4.4.3 The Helderberg route

Winery G

Winery G grows its grapes in an organic and biodynamic way, therefore grapes yearly, were not negatively affected by the drought, and from 2015 -2018 there was a year on year increase in the total tonnage harvested. Certain cultivars did experience a slight decrease in yield, however this was countered by other cultivars, which experienced an increase in yield. The overall result was that Winery G experienced an increasing yield trend during the most recent drought. Cabernet Sauvignon was one of the cultivars which experienced a year-on-year increase in yield during this period. This increase is illustrated in the figure below.

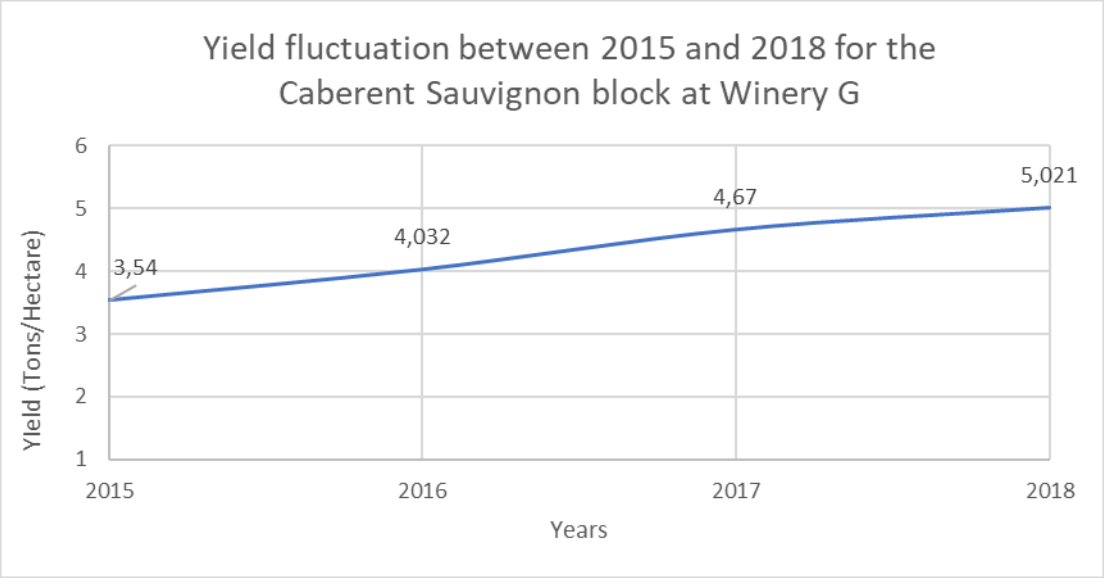


Figure 4.3: Yield fluctuations Between 2015 and 2018 for the Cabernet Sauvignon block at Winery G

Figure 4.3 illustrates that during the most recent drought, the yield increased from 3.54 tons/hectare in 2015, to 5,021 tons/hectare in 2018. Respondent seven said that this increase in yield is due to the fact that the vines are grown in an organic and biodynamic manner, and therefore the soil is very healthy and loose. It works like a sponge, which means a large proportion of water is absorbed into the soil, which is key during a drought. Chemical fertilisers, herbicides or pesticides are linked with increasing the salinity in the soil, as well as drying the soil out. Winery G only used cattle manure and compost to fertilise the vines, which meant the soil did not get dried out any further during the drought period. This could possibly have led to an overall increase in yield across this period.

Winery H

Respondent eight said that there was no significant change in yields during the most recent drought period for most of the red grape cultivars. They went on to say that both Cabernet Sauvignon and Cabernet Franc handled the drought the best. It was also mentioned that the drought did not have a significant impact on yield due to the location, and the fact that the vines did get some irrigation during the drought. After analysing the yield figures that the respondent provided, it is clear that there is a discrepancy between what the respondent said and the actual yields.

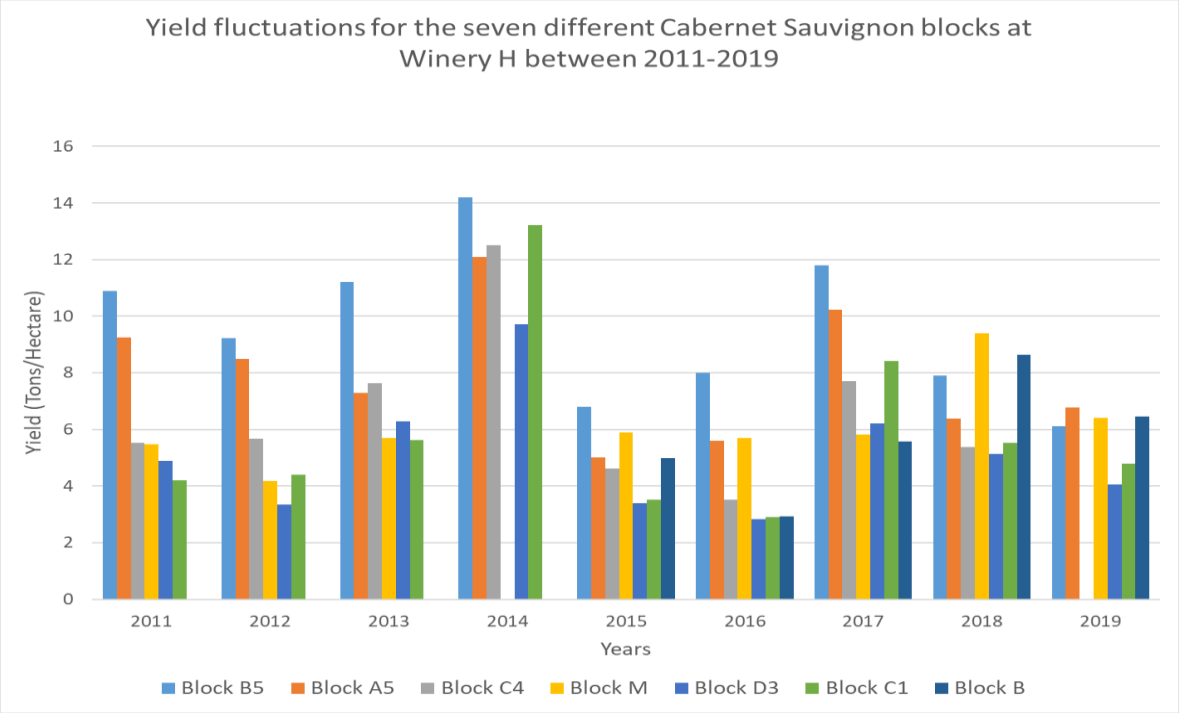


Figure 4.4: Yield fluctuations for the seven different Cabernet Sauvignon blocks at Winery H between 2011-2019

Figure 4.4 gives a graphical illustration of the yield fluctuation between 2011 and 2019. From this figure, it is clear that certain blocks have had larger yields in some years as well as lower yields in others. A trend that can be observed is that yields peaked in 2014, as five out of the seven blocks showed record yields during this period. It is also clear that there was a significant decrease in yield for most of the blocks, from 2014 to 2015. The blocks which experienced the largest decrease in yields between 2014 and 2015, were blocks C1 and D3with a decrease in yield of 73.32% and 64.98% respectively. 2016 was another year of lower than average yield, nevertheless, the yield did increase in 2017, and reverted to what can be considered the average yield. It can be said therefore that there was a significant decrease in yield for the first two years of the drought (2015 and 2016), however from 2017 onwards, the yield did recover to yield achieved in average rainfall years.

4.4.4 The Stellenbosch Berg route

Winery I

Respondent nine said that between 2015 and 2019, there was a decline in total yield for most cultivars. Shiraz however had the largest decline in yield and the total yield for Cabernet Sauvignon declined by 5-12% between 2015 and 2019. The lowest yield for Cabernet Sauvignon was experienced in 2018, where there was a 12% reduction in yield. The respondent said that this reduction in yield was linked to the compounding effect of the drought from 2015 onwards. Malbec was the only cultivar to have an increasing yield trend during this period.

Winery J

Winery J experienced a significant decrease in yield for all their cultivars, however the cultivars which experienced the largest decline in yield were Chardonnay and Merlot, followed by Cabernet Sauvignon and Sauvignon Blanc. The yield for the Cabernet Sauvignon Block decreased by two to three tons/hectares which does not seem that significant, however it worked out to roughly a 20-30% decrease in yield between 2015

and 2018. The Cabernet Sauvignon bunches were much smaller, and this is the main reason why the yield decreased, even though the number of bunches per vine remained the same during this period. 2017 was the worst year for Cabernet Sauvignon yield and juice volumes, as the water supply ran out in the previous year and so no supplementary irrigation could be provided to the vines from 2016 onwards.

Winery K

Winery K was adversely affected by the drought in terms of both yield as well as juice volume extracted from the grapes. Between 2016 and 2019 none of the Cabernet Sauvignon vines received any irrigation, which caused several vines to die from water stress; there was a noticeable crop reduction in many of the cultivars. Shiraz experienced the largest drop in yield, followed by Pinot Noir and then Cabernet Sauvignon. Cabernet Sauvignon decreased from 7.5 tons/ hectare in 2014 to 5.3 tons/ hectare in 2015 and a further decline in yield in 2016 to 4.2 tons/ hectare. The decline in yield was not the only worrying factor; there was also a 25-35 % decrease in the amount of juice extracted from the grapes, which meant that the juice extracted fell from approximately 650 litres to 450 litres. This meant that the number of bottles of wine that could be produced decreased significantly, and therefore it can be said that the impact of the drought was two-fold; it decreased the total volume of juice extracted per ton of grapes, as well as decreased the tonnage per hectare.

4.4.5 The Stellenbosch Valley route

Winery L

Respondent twelve said that the yield from Cabernet Sauvignon had been severely affected and had decreased steadily from 2015 to 2018. The respondent did however only give a percentage decrease in yield between 2016 and 2017, and 2017 and 2018 – this was 15% and 19% respectively. The respondent went on to say that the two main reasons why there had been a significant decrease in yield, was due to fact that the vine was grown without any additional irrigation and so they felt the full stress of the drought. Another reason for the decline in yield was that every year during the drought vines died, so the total number of vines producing grapes decreased over this period.

Winery M

Respondent thirteen did not disclose exact figures for the different blocks, however they did mention that 2014 was a very wet year. This caused the 2014 harvest tonnage per hectares to be larger than normal, however 2015 was the first year of the drought which caused the yield to decrease. The 2016 yield for Cabernet Sauvignon decreased to 5.5 tons per hectare. From 2016 the drought started to have a knock-on effect, and the lack of rain after harvest caused young vines to struggle. The stress accumulated and 2017 was the first year where there was a significant decrease in yield, of 10-25 % in the different Cabernet Sauvignon blocks; the 2018 and 2019 yield were similar to 2017. The decrease in yield took place even though the vines received supplementary irrigation.

After analysing the data from the different respondents, it is evident that certain wineries were affected to a greater extent by the drought, compared to others. This proves that once again the effect of the drought is site-specific, and certain terroirs will cause vines to experience a larger fluctuation in yields compared to others.

Nevertheless, it can be deduced that wineries C and G experienced an overall increase in yield, and wineries E and F yields remained fairly constant during the most recent drought period. For certain years, the remaining nine wineries experienced a noticeable decrease in yields of between 5% - 73.32%. From the information given by the different respondents, it can be noted that Winery H experienced the most significant decline in yield of 73.32% between 2014 and 2015. The sub-route which seemed to handle the drought the best in term of yield, was the greater Simonsberg route, as three out of the four wineries experienced a flat or increasing yield trend during this period. In conclusion, it can be noted that the majority of the farms were negatively impacted by the most recent drought in terms of yield, however this trend only affected nine out of the thirteen wineries and therefore it is critical to review each winery in isolation rather than as a collective.

4.5 Parameters used to measure quality

Many viticulturist and winemakers stand by the truism that you can make bad wine from good grapes, but you cannot make good wine from bad grapes. The question that needs to be answered however, is what is a so-called “good grape”, and is there any way of determining whether a grape/bunch of grapes is essentially good or bad. The term quality, as mentioned before, is a very subjective concept, however after asking respondents the question of what is grape quality and how can it be measured, it was clear that there are certain parameters, as well as different techniques, that could be used to determine the quality of a grape/bunch of grapes. Certain trends occurred in the answers that the different respondents gave when they were asked how they measure wine grape quality in Cabernet Sauvignon grapes.

Ten out of the thirteen respondents said that grape quality can be determined through visual appearance and taste. Respondents three, four, six and twelve mentioned that quality can be determined through visual appearance and taste, however this knowledge is built up over many years in the vineyard. Each harvest is slightly different, and so their experience, that has built up over time, has helped them determine which grape/grape bunches are better in terms of quality than others. Tasting the grapes is used as an organoleptic assessment – it includes the assessment of flavour, smell, appearance, and mouthfeel of a grape. These characteristics are used to determine quality, however learning how to interpret these characteristics takes years of experience. Respondents 6 and 11 said that the observation of overall health in terms of the percentage of bunches affected by rot or disease in a block, is another way to determine the quality of grapes from a particular season. Respondents 5 and 8 said that there is a direct relationship between the health of a vine and the quality of the grapes that are produced, therefore, a vine that is infected with the leaf roll virus tends to produce grapes of lower quality; the virus restricts grapes from ripening and certain parameters are negatively impacted.

Eight of the respondents mentioned how even though quality might be subjective, there are certain parameters which can be used to verify grape quality. Visual appearance and taste were mentioned as being one of the initial ways in which these parameters are assessed, however there are analytical tests that can be used to measure these parameters more accurately. Respondent one stated that these analytical tests can be grouped into three main categories which are physical, biological, and chemical. Under each one of these category tests

are specific parameters, which can assist in measuring grape quality. These parameters can be found in the table below:

Table 10: specific parameter to measure grape quality

Physical	Biological	Chemical
• Berry size	• Percentage of rot or disease	• Sugar accumulation
• Bunch size	• Skin thickness	• Fructose-glucose ratio
• Berry colouring	• Pulp to juice ratio	• Titratable acids
• The number of seeds	• Tannin structure	• Juice pH
• Seed hardness		• Sugar to acid ration
• Seed colouring		• Total phenolic compounds
• Pulp integrity		• Total anthocyanins
		• Tannin content

The respondents mentioned all these parameters, however certain parameters were discussed in more detail than others. There were seven parameters which all the respondents deliberated on in their answers relating to how grape quality, in particular Cabernet Sauvignon grapes, can be measured. These seven parameters were: grape size, grape colouring, percentage of rot or disease (overall health), sugar accumulation, juice pH, total phenolic compounds, and total anthocyanins, linked to grape colouring. Another factor that was mentioned by all the respondents was that of consistency between different grapes in a bunch, as well as different bunches on a vine. Without consistency, grapes will not be homogenous, and will contain different properties that will cause the overall grape quality to be lower.

Grape size is one of the most important parameters which can assist in determining the quality of a grape. It was clear in the literature review that there has been extended debate around the topic of whether the size of the grape influences the quality. Respondents five, nine, eleven and thirteen mentioned how larger grapes tend to be diluted and watery in taste, and this causes the wine to be slightly lighter in style. This leads to a less structured wine and can be problematic as it is not the typical style most winemakers aim for when creating a Cabernet Sauvignon. Smaller Cabernet Sauvignon grapes produce more concentrated juice with better structures, that cause more robust flavours and aromas. This can also be linked to the higher skin to flesh ratio, which is necessary for better quality. Smaller berries have thicker skins which protects them, and this means fewer berries get damaged during harvest. Smaller grapes are more sought after than bigger berries due to these reasons, although respondents 4 and 10 both said that even though smaller berries are more sought after in terms of quality, if the berries become too small they can start to become jammy as they ripen too fast. According to respondent One, the ideal size for a Cabernet Sauvignon grape is between 1.51 g and 2.00 g per berry, with a bunch weight of around 60-80grams.

Grape colour is the next physical parameter that needs to be enlarged upon. Grape colour can be determined visually by walking through the vineyards during harvest, however the more accurate approach to assessing grape colour is done by measuring total anthocyanins. Anthocyanins are a group of naturally occurring pigments that are responsible for the colouring in grapes and are located mainly in the skin but also occur in the flesh. The consistency of grape colouring in a bunch is important, and this will relate to the size and shape

of the bunches. Grape colouring is especially important in red wine cultivars such as Cabernet Sauvignon, as it is responsible for the flavours as well as the structure of the wine. There was a consensus among the respondents that an increase in grape colour coincides with an increase in aroma intensity, an improvement in phenol structure, and an increase in overall wine quality. Ten of the respondents said that they perceived better grape colour i.e. higher total anthocyanins as being one of the signs of better grape quality.

Sugar accumulation in a grape is one of the main features of the ripening process and is a measure to determine when grapes should be harvested. Sugar accumulation and the rate at which it accumulates influences the quality of the grapes. Respondent eleven stated that Cabernet Sauvignon grapes should be picked between 23-24 degrees balling as that is when they are optimally ripe in terms of sugar accumulation and would have their best quality. The respondent went on to say however that the speed at which the sugar accumulates is also important, because if it accumulates too rapidly, certain quality issues can arise. An example would be that it will cause an increase in fructose rather than glucose, which can lead to stuck fermentations; that is why the fructose-glucose ratio is also an important determinant of quality. Another issue that can arise is that a grape can be sugar ripe but has not reached a state of phenolic ripeness, which means grape quality will not be optimal.

The percentage of rot or disease within bunches across a block of vines is a biological parameter that can be used to assess grape quality. There is no test needed to determine this parameter, as disease and rot can be identified by walking through the block of vines around harvest. The percentage of rot is often linked to the distribution of the grapes within a bunch. Respondent twelve said that if the berries are loosely distributed within a bunch, it allows them to develop evenly, and reduces the chance of rot and fungi, as excess moisture cannot form between grapes. When grapes are loosely distributed, it allows airflow as well as sunlight to occur between the grapes, which restrict moisture from collecting between grapes. Loose berries therefore often indicate better quality bunches, as they tend to reduce the amount of rot and fungi across bunches of grapes.

The total phenolic compounds present have a unique but important role to play, as they are primarily responsible for the sensory characteristics of both grapes and wine; they are responsible for certain sensory properties such as aroma, colour, flavour, bitterness, and astringency, and are therefore important measurements to determine the quality of grapes. All the respondents said with Cabernet Sauvignon, the higher the total amount of phenolic compounds, the better the quality. Not all respondents tested for total phenolics however, as these tests need to be conducted in a laboratory. According to respondent thirteen, a single sample panel of phenolics costs over R200, and numerous samples are needed to get an indication of the average amount of phenolic compounds within a single block. In the respondent's opinion, the benefits of these tests far outweigh the costs as it gives the winemaker valuable information that they can use to their advantage to further improve the quality of the end product.

Grape quality can also be judged through the end product. Respondents 6, 7, 11 and 13 mentioned that the quality of the end product is directly linked to the quality of the grapes. Respondent six expanded on this and said that “grape quality is of utmost importance and probably 90% responsible for the quality of the final wine.

Winemakers do have a role to play but it is a much less significant role compared to the quality of the grapes. Quality wines are created due to an important symbiotic relationship between fruit quality and the winemakers' influence". Respondents 12 and 13 mentioned that grape quality will influence the number of awards as well as ratings that wines achieve.

Price is the last measure for grape quality that respondents deliberated on. The majority of the respondents mentioned that the wineries that they work at do not buy or sell grapes and therefore for them price can be a grey area, as the grapes are grown, harvested and used to make wine This all takes place on the farm and therefore no transaction takes place. The price of grapes therefore is not used to determine the grape quality at these wineries. Respondent Three mentioned that Winery C does buy in grapes from outside farms, however this is done on a contractual basis, and consequently the price is determined in the prior season. Respondent Three also mentioned that only in extreme cases has the price been influenced by the grape quality. This is more likely to occur if the quality is extremely poor, such as a large proportion of unhealthy grapes. As quality cannot be directly measured, it is highly unlikely that so-called better-quality grapes will impact the price set in the prior season. Respondents fourteen and fifteen discussed how the price of wine grapes have increased by around 12-18 % each year during the drought years (2015-2018). This is more than the usual increase of around 7%, as smaller quantities are being produced, but also due to the so-called improved berry quality; both these factors have led to the increase in the grape prices. South Africa also has relatively low production costs compared to many of the other countries, so in the past, wine grapes have been sold at lower prices compared to other countries. This means that grape growers have room to increase the price, especially if the grapes are of high quality.

As mentioned earlier, grape quality can improve or reduce the quality of the wine being produced. The price of wine can therefore be a reflection on the grape quality, even though many factors influence the quality of the wine. Nevertheless, the grape quality is one of the more prominent factors in this regard. Respondents five, nine and eleven said that the relationship between quality and price is complex, and even though the price of their wines has increased, the increase is predominantly due to the lack of volume of juice extracted from grapes, rather than the "better quality juice". On the other side of the spectrum, Respondent six spoke of the work of Richard Jennings, who investigated the relationship between price and quality, and found an exponential relationship between the price of wine and the quality of wines, according to their ratings which the wines have received from different rating agencies. It can therefore be argued that both quality and quantity influence price. As quantity can be directly measured, it is often seen as being responsible for the change in price; Richard Jennings showed that when quality increases, price increases exponentially, therefore the price can be used to a certain extent to measure quality.

4.6 The impact of droughts on Cabernet Sauvignon grape quality

4.6.1 The Bottelary hills route

Winery A

Grape quality improved in terms of the parameter of berry size. As a result of the water stress caused by the drought, the vines produced smaller berries, which meant there was a higher skin to pulp ratio. This led to juice extracted being more concentrated, which resulted in more flavour and aromas; this is why the smaller berries improved the grape quality. The grape quality also improved during the drought because the bunch shape became longer and thinner. This meant the berries in bunches could ripen more evenly, as the sunlight could get to the middle of the bunches, which allowed berries in the middle to ripen at the same speed as the berries on the outside of the bunches.

Grape quality was better in terms of berry consistency, especially in areas with soil that contained clay. The vines planted on soils with a higher clay content, during a year of average rainfall, tend to have unbalanced canopy growth. This results in shoots that vary in diameter, and berries often are not consistent through the vine. In the drier years however the shoot growth was slightly restricted, which meant shoots were more consistent. This leads to the bunches being more homogenous in these areas. If the shoots vary in size, it causes some bunches to ripen unevenly as certain grapes will remain green while others will become overripe, as the thickness of the shoot can affect the grapes bunches maturity period and the overall quality of the grapes. During the most recent drought therefore, bunches ripened more evenly as the vegetative shoot diameter was more consistent through vines. This meant the grape quality experienced was better quality as the bunches ripened more evenly which meant they were more homogenous.

The best quality grapes during the most recent drought were said to come from the 20-year-old block of Cabernet Sauvignon. This was because they had the best overall colouring and the juice from their grapes was the most concentrated. The grape quality from the other blocks also improved. The most noticeable improvement in grape quality was associated with the vines with shortened trunks. Respondent one also said that during the drier years, the Cabernet Sauvignon tasted a lot bigger and bolder and had a better tannic structure which could improve the age-ability of the wines in the years to come. In conclusion, the respondent said that even though the grape quality has improved during the drought it will not be able to counterbalance the decrease in yield, as the decrease in yield will have a larger negative impact on potential income compared to the increase in grape quality.

Winery B

Respondent two mentioned that between 2015 and 2019, there has been an increase in quality on sparkling base wine and most red wine cultivars, but a general decrease in grape quality on white wine cultivars. The grape quality of the different cultivars during this period was rated using a Likert scale. The cultivars that saw an overall decrease in quality were Sauvignon Blanc (5), Muscat (4), Gewurztraminer (4), Riesling (4), Semillon (3), Shiraz (1), and Chenin Blanc (0). The cultivars which experienced an overall increase in grape quality were Carignan (2), Cabernet Franc (2), Gamay (2), Cabernet Sauvignon (1.5), Touriga Nacional (1),

and Merlot (1). Base wine made from Chardonnay, Pinotage, Pinot Noir, and Pinot Meunier also improved. Whites grape cultivars tended to be affected more, mainly because drought coincides with dry heat, which results in low acidity and deprives white wines of lively freshness. Grapes responsible for the production of base wine are picked early enough to be saved from this. Water stress also improved the overall health of the berries produced. Red wines are less dependent on acidity, and the drier conditions resulted in smaller grapes, which promoted riper flavours/tannins and greater aroma intensity.

The harvest date became earlier due to the drought. This however was the opposite for vines that are infected by the leafroll virus. The water stress from the drought caused the virus to show substantially more virus symptoms, which caused ripening to slow down and even prevented certain bunches from fully ripening. It can be argued that the drought did increase leafroll virus symptoms, which meant those vines struggled in terms of quality, due to additional stress. Nevertheless, it can also be argued that the impact of the drought was cultivar specific, and that Cabernet Sauvignon did experience a slight overall improvement in grape quality at winery B. Respondent two said that the decrease in yield would cause a decrease in potential revenue in the years to come, however at the same time the improvement it grape quality will restrict this decrease; this phenomenon will only hold in the short term. The respondent concluded by saying that during the drought period, the lower yield was more economically damaging and therefore the decrease in yield was not counterbalanced by an increase in grape quality.

4.6.2 The Greater Simonsberg Route

Winery C

Respondent Three mentioned that 2015, 2017 and 2018 produced excellent quality overall, especially when it came to Cabernet Sauvignon and Shiraz. They said that the drought had a role to play, as water could be administrated to the vine when it was necessary, as the winery had sufficient supply of water for irrigation, despite severe water restrictions. 2016 was a bad year in terms of quality, but this was not due to the drought – it was related to the extended hanging time, due to the sluggish sugar accumulation in the berries that lead to tasteless grapes. The grape quality for Cabernet Sauvignon, in particular, was also excellent in 2015, 2017 and 2018, as the berries were smaller in size with better colouring, which meant anthocyanins increased, the juice extracted was more concentrated and had a more predominant flavour and aroma profile. These are important in producing a quality red wine as the thicker skins provided a better tannin structure which allows the wines to age better. This is more important in red wines rather than in white wines. So far, the wine quality of the 2015 vintage has been exemplary, and has won numerous awards although the wine quality of 2017 and 2018 is still too young to determine its quality. In Respondent Three's opinion, the grape quality of Cabernet Sauvignon has generally increased during the drought period, and in most years the yield also increased, with the exception of 2016.

Winery D

Respondent Four said that the vines that received supplementary irrigation during the drought suffered less from water stress, which meant these vines could focus on quality. The vines without irrigation tended to get

stressed to the point where the grape development was affected, which caused the quality to be poor. Respondent four said that the Cabernet Sauvignon vines received irrigation during the drought, which meant that the grapes could develop fully and the slight water constraint during ripening was ideal for flavour and tannin development in the grapes. This being said, the grapes were smaller and the juice more concentrated. That does not necessarily mean better quality. The respondent argued that quality is a subjective term, that it is difficult to quantify, and that the term quality is often used for marketing purposes. The respondent concluded by saying that the decrease in yield would not be counterbalanced by an increase in grape quality.

Winery E

Respondent five said that the grape quality between 2015-2019 was notably better than the previous couple of years. This was determined by tasting the grapes before harvest, as well as by running numerous tests which were used to indicate the quality of the grapes. The improvement in grape quality during this period was determined by better grape colouring throughout all the Cabernet Sauvignon blocks, in addition to the grapes having a firmer tannin structure. The grapes were also much smaller in diameter and tended to have thicker skins and more concentrated juice. One block of Cabernet Sauvignon in particular, which is planted on loose soil with good water retention, produced the best quality Cabernet Sauvignon grapes, and was responsible for producing the most structured wine over the last four years. This particular block has been known to be wetter than the other block in the past and in wetter years vines suffered from anaerobic conditions. The drought had an overall positive impact on this block in particular. Blocks four and five are situated on steep slopes and experienced a decrease in terms of both the grape quality and quantity during the drought. This was because the soil is shallow, and the steep slopes have caused low infiltration rates. Moisture tends to run off down the slope rather than getting soaked into the soil, therefore during the drought these vines were put under extreme stress which caused several vines to die. 2015 and 2017 were the two stand-out years in terms of quality, especially for Cabernet Sauvignon grapes, as they had good colouring which coincided with an improvement in phenol structure and an increase in aroma intensity. There was also better tannin extraction, which allowed the juice to be turned into bolder wines, which is the style of Cabernet Sauvignon that the winery aims to produce. The drought has improved the balance between vegetative growth and reproductive growth, which can often be an issue among the Cabernet Sauvignon blocks, especially in younger vines. They tend to focus on vegetative growth more than reproductive growth, which led to a lower tonnage per hectare poor grape quality, as there is a lack of consistency between bunches.

Even though the quality of the Cabernet Sauvignon grapes was said to be better, it was mentioned that the drought period caused an increase in the rate of infection of the leafroll virus among red wine grape cultivars. This is due to the increased stress levels of the vines during drought periods. In the long run, this can cause the fruit quality to decline, as the fruit chemistry will be different in the vines infected with leafroll compared to the vines that are not infected. It will cause sugar accumulation to occur at a much slower pace, and increases hang time for the grapes, leading to a decrease in quality. It will also cause the juice pH to be higher, while titratable acidity will be lower. The decrease in water content in the soil caused the vines to become slightly stressed, which is what wine grapes, especially Cabernet Sauvignon grapes relish. This is the likely reason

why the quality of the grapes was better during this period. Respondent five concluded by saying that at Winery E, the overall quality did improve, and that in their opinion the quality did increase by a greater proportion than the change in tonnage between 2015 and 2018.

Winery F

Respondent six argued that quality is very difficult to quantify, and it is therefore difficult to say whether quality has improved or not as the quality is made up of many different aspects. The respondent did mention however that the drought leads to vines producing smaller bunches and smaller berries. Thus the knock-on effect on the wine for red wine cultivars is that your skin to flesh ratio was higher during the drought, leading to intense, concentrated wines with great tannin profiles. As for white wines, they spend less time on the skins than red wines and are therefore less affected. The respondent concluded by saying that there is a general consensus that vineyards in Stellenbosch have experienced a decrease in yield, which has led to an improvement in grape quality. The respondent does not agree with this sentiment as although they have observed a shift in quality, they stated that it will be difficult to determine whether it was an improvement or not.

4.6.3 The Helderberg route

Winery G

The grape quality of all the red cultivars was high between 2015 – 2018, in particular Cabernet Sauvignon. Certain white grape cultivars, such as Chardonnay and Verdelho, struggled somewhat in terms of both yield and quality; this was because there were several hotter days in the winters of 2017 and 2018, which caused these two cultivars to bud early. The cold weather returned however, and the vines went back into a dormant stage. This negatively affected the vines, which in turn affected the grapes, but in the end the red cultivars were not affected by this. The quality of the Cabernet Sauvignon grapes improved in terms of size, colour and flavour; the grapes were smaller as well as more consistent in size throughout the bunches, which meant the grapes had more concentrated flavours. The grapes had better colouring, which means that the total anthocyanins increased. The Cabernet Sauvignon grape quality between 2015 and 2018 was measured using a five-point Likert scale and the results were as follows:

- 2015 yield was smaller compared to 2014 but grape quality was better (3.5)
- 2016 yield increased and quality was good (3)
- 2017 yield increased and quality was very good (4.5)
- 2018 yield increased and quality was as good as 2017 (4.5)

It can therefore be deduced that both yield and quality for Cabernet Sauvignon grapes improved between 2015-2018, as they experienced a positive trend in this regard. Consequently, winery G showed that yield and quality can increase together, which goes against the so-called negative relationship which is often associated with wine grapes.

Winery H

Between 2015 - 2018, the quality of the grapes produced was reportedly better than normal in most respects. Cabernet Sauvignon did experience the largest improvement in the quality of all the red grape cultivars, as it had good even colouring, and smaller, loosely distributed berries within bunches compared to normal. This reduced disease and rot, however, sunburn was an issue in some blocks of Cabernet Sauvignon due to the dry heat experienced during ripening. It can therefore be said that the Cabernet Sauvignon grape quality in most respects was positively impacted by the drought, however there has been a steady improvement in quality over the years, which is also due to better technology being created, new rootstocks being introduced and better canopy management programs being developed on an ongoing basis. A drought that happened in the 1990s would have had a much larger impact than it would have today. It can therefore be deduced that this is partly due to the continual improvement in technology and viticulturally practices that have discovered over the years.

4.6.4 The Stellenbosch Berg route

Winery I

Respondent nine mentioned that Cabernet Sauvignon grape quality fluctuated between 2015 – 2019. The grape quality in most respects has improved during this period, however this is not exclusively due to the drought, although it is one of the prominent factors. The Cabernet Sauvignon grape quality was exceptional in 2015 and 2017, as the grapes were smaller and ripened more evenly, in addition to having better colouring and less rot compared to other years. In 2018 there was more rain during the summer months, which caused high fungus pressure leading to poorer quality. It can be said that drought conditions increased grape quality, however no two harvests are the same. It cannot be assumed that grape quality will automatically be better in the drier years, as there are many other factors that need to be considered. Timing is crucial, for example the drier conditions between February and March are beneficial for the overall quality of Cabernet Sauvignon grapes, as it reduces rot and allows the grapes to ripen evenly. This is needed for exceptional grape quality, although a drier period after harvest can affect the quality of the grapes produced in the following year.

The respondent also stated that the market tends to prefer Cabernet Sauvignon wines with red fruit characteristics such as raspberries or strawberries, and due to the drought stress, Cabernet Sauvignon wines produced at the winery between 2015 and 2019 showed more red fruit characteristics - for that reason quality has improved. Winery I focuses on grape quality rather than tonnage, so the drought has positively impacted the quality and slightly decreased the tonnage per hectare. It can therefore be argued that during certain years (during the most recent drought of 2015 - 2017), the decrease in the quantity of Cabernet Sauvignon has been counterbalanced by the increase in the quality of wine grapes. In 2018 however the quality was good, but it is likely that it did not improve by as much as the decrease in tonnage.

Winery J

Respondent Ten said that the drought did not have much impact on the grape quality for the first two years of the drought, however there was a significant change in 2017 as the berries were much smaller and the bunches were much more concentrated than in 2016. This meant that the flavours were intensified although, this being

said, there were certain Cabernet Sauvignon vines that suffered more from the drought. This caused their bunches to be much smaller and the vine sap in the grapes became jammy, which is associated with low grape quality. The Cabernet Sauvignon block also suffered extensively from leafroll virus symptoms from 2017 onwards, which impacted the grape ripening process. In the respondent's opinion, the Cabernet Sauvignon grape quality remained constant between 2015-2016, however from 2017 onwards there was a significant change in quality. It is nevertheless hard to say whether the overall quality was better or worse, and for that reason the decrease in yield was not counterbalanced by an increase in grape quality between 2015-2019.

Winery K

Respondent eleven said that the overall grape quality across all the cultivars decreased slightly from 2015 to 2019, which was due to the severe water stress experienced by the vines. The red grape quality overall decreased less than that of the white cultivars. The Chardonnay blocks experienced the most noticeable reduction in grape quality and suffered badly from sunburn. The Cabernet Sauvignon grape quality improved in some respects, for example, the grapes were smaller which meant more concentrated flavours. There was also a shift in the aroma profiles of the Cabernet Sauvignon grapes towards dark fruits, such as black currants and plums, however there were issues of high fructose concentration which caused stuck fermentations to occur. The drought also caused stress characteristics to come through in the grapes, especially during 2017 and 2018, where the sugar accumulation just stopped at 21 degrees balling and would not ripen any further. In 2017 there was a complete reversal of sugar, and the glucose-fructose ratio swopped, and fructose became more prominent than glucose. This caused stuck fermentation to occur, which meant fructophilic yeast was needed to make sure fermentation took place. This increased production costs as the fructophilic yeast is slightly more expensive than the normal yeast. 2018 was also a difficult vintage, although less difficult than 2017, but still not as straight forward as normal. It can be argued therefore that the decrease in yield was not counterbalanced by an increase in grape quality between 2015-2019.

4.6.5 The Stellenbosch Valley route

Winery L

Respondent twelve argued that grape quality is difficult to quantify, as there are grey areas due to the many factors that make up grape quality. The respondent stated that the drought impacted the quality of the grapes, although in his opinion the drought did not necessarily improve the overall grape quality. The respondent did say however that certain aspects of Cabernet Sauvignon grapes were better; the bunches were smaller and were comprised of smaller and looser grapes which indicated more concentrated juice, thicker skin, and more flavour compound. In total this does not mean better quality as it is not a linear equation. Even though 2017 and 2018 harvests had smaller berries and smaller bunches (often seen as better grape quality), there was an imbalance between glucose and fructose which was problematic for fermentation. This imbalance leads to ineffective fermentation, and in addition, residual sugar was slightly elevated, which can be seen as a negative trait in grape quality. It can be argued that certain quality parameters improved, however others deteriorated and although it is clear that yield decreased , it is not possible to state unequivocally that grape quality improved, which means the decrease in yield cannot be counterbalanced by the increase in grape quality.

Winery M

Respondent thirteen said that the grape quality fluctuated between 2015-2019 but in general the quality was slightly better. Cabernet Sauvignon was one of the standout red wine cultivars in terms of quality 2015, 2017 and 2018 were exceptional years in terms of grape quality as the grapes were smaller had much higher anthocyanin concentration as well as higher total phenolic compounds. The knock-on effect of the drought started to impact the vine's permanent structure, and this contributed to below-average quality in 2019. The respondent alluded to the fact that that it is hard to quantify quality over a drought period, as each harvest will be different. An assessment on whether the increase in grape quality could counterbalance the decrease in yield needs to be done yearly. In 2015, 2017 and 2018 the decrease in Cabernet Sauvignon grape yield was counterbalanced by an increase in grape quality, however this was not the case in 2016 and 2019, as the grape quality was not as remarkable as the other three years.

4.6.6 Summary regarding the change in grape quality

After analysing the information given by the different respondents, it is clear once again that each winery has been impacted differently by the drought in terms of the quality of their Cabernet Sauvignon grapes. Certain respondents said there has been a notable increase in grape quality during the drought period, whereas other respondents said that there has been a significant decrease in grape quality. This is linked to a wide array of different factors but in essence it boiled down to the severity of the water stress which the vine experienced, as well as how well the vines handled the water stress. Eight out of the thirteen respondents said that overall grape quality improved during the drought in terms of certain parameters such as smaller looser berries, higher skin to pulp ratio, more concentrated juice in terms of flavour and aroma profiles, better colouring and better tannin structures. Respondents four, six and twelve said that it was difficult to say whether overall grape quality improved or not, and only two respondents said that overall grape quality decreased. This was due to grapes becoming too small, which meant they became jammy, as well as an increase in the fructose concentrations, which caused stuck fermentations to occur.

It was clear from the findings that the relationship between quality and the economic value of wine grapes is subjective as well as very complex. Therefore, it can be concluded that the relationship between quality and the economic valuation will always be difficult to prove, due to various variables that come into play as well as the fact that many of them are not measurable. It was also mentioned by a couple of the respondents that the increase in quality will not filter through into the market price of the product. Therefore, the overall winner will be the consumer as they will get better quality wine at the same price point as prior vintages.

Chapter Five: Summary, Conclusion, and Recommendations

5.1 Summary

The aim of this study was to analyse the impact of droughts in the Stellenbosch region on both the grape yield and grape quality of the Cabernet Sauvignon wine grape cultivar. Both these factors are vitally important in the production of any agricultural product including that of wine grapes. The yield and the quality of the grapes produced in a particular season have a direct impact on a winery's potential revenue, which is why both these factors must be monitored as well as recognised continually. The term grape quality is undoubtedly subjective, which makes it somewhat problematic to measure, and therefore certain parameters are needed to determine grape quality. The grape yield on the other hand, can be measured simply and straightforwardly, and it is therefore much easier to keep a record of the change in grape yield over time, in comparison to that of the change in grape quality.

Given the intricate nature of wine grape cultivation, it is clear that numerous factors are interconnected, and have a direct impact on wine grape production. Chapter Two uses existing literature to unpack the interconnectedness of these factors, as well as to determine how these factors influence both grape quality and yield during times of drought. This chapter is broken into two segments, the first part of the chapter begins by describing the term terroir, in particular climatic factors such as temperature and precipitation, in order to analyse how these factors can influence wine grape production. It then examines how these factors have changed over time, and how certain scenarios can influence wine grape yield as well as grape quality in the Stellenbosch region. The second part of this chapter starts by analysing specific aspects of Cabernet Sauvignon as a cultivar, which are used as a guideline for grape producers. It then investigates how the quality of wine grapes, in particular, Cabernet Sauvignon is measured. The chapter ends by investigating the different viticultural practices used to influence wine grape quality, coupled with a discussion on how drought and water availability impact the yield as well as the quality of grapes, in addition to wine production.

After unpacking and evaluating the existing literature surrounding this topic, it was necessary to start dissecting the different methods that would be used to collect and analyse the data for the study. Chapter Three starts by discussing the rationale behind this study and states questions that this study aims to answer. It then explains why Stellenbosch was selected as the geographic area of study, followed by the reasoning behind the research methods that will be used, as well as the nature of the data that will be collected for this study. Finally, it conveys the tools that were used to analyse the data which was used to create the findings of this study.

Chapter Four is essentially the backbone of this study, as this is the chapter that intends to answer the main question of this study, which is whether or not a decline in grape yield can be counterbalanced by an increase in grape quality, in particular of the Cabernet Sauvignon grape cultivar, during a drought period in the Stellenbosch region. The chapter four is broken down into five subsections. It starts by discussing the general background, as well as giving some context to the wineries included in the study. Secondly it analyses what viticultural practices can be implemented during drought periods to minimize the negative impacts of drought conditions, as well as to potentially optimise Cabernet Sauvignon grapes in terms of both quality and quantity.

Thirdly it discussed how droughts affected Cabernet Sauvignon grape yields. Fourthly it analysed how the respondents view grape quality, in particular Cabernet Sauvignon grapes, and what parameters they use to measure quality. Finally, it discussed whether these quality parameters used to measure quality increased or decreased during drought periods. This served to provide material to try and establish whether the decrease in quantity of the Cabernet Sauvignon grapes has been counterbalanced by the increase in quality of wine grapes during droughts.

5.2 Conclusion of the findings

The five major viticultural practices that respondents argued could help minimize the negative impacts of drought conditions, as well as possibly optimise Cabernet Sauvignon grapes in drier periods, were an adjustment of irrigation practices, the implementation of probes to measure soil moisture, the usage of cover crops and mulching, and finally the adjustment of canopy management. Each of these practices had certain advantages, however most of them also had drawbacks, many of which came in the form of additional input costs. With irrigation, it can be argued that the wineries with vines under irrigation should manage water carefully, in order to have sufficient water to be able to irrigate during post-harvest; this was said to be the most critical time for the survival of the vines. It was also argued that the wineries that had water to irrigate during the drought suffered a smaller decline in yield. As regards fertilisation, it was argued that organic fertiliser, such as animal manure, was a better alternative than chemical fertilisers, as chemical fertiliser contain salts which dried out the soil further. Cover crops and mulching should be used to improve the infiltration of water into the soil, as well as soil moisture retention. It was argued that canopy management and an adjustment of pruning techniques could minimize the negative impacts caused by droughts. In this regard, it seemed that the Italian pruning method, Simonit & Sirch is beneficial in both above-normal rainfall years and drought years, as it can potentially increase a vine's lifespan. This reduces production costs as well as potentially allowing the vines to produce higher quality grapes for an extended period, as the vine has an extended mature stage.

The respondents argued that it would be unlikely that the winery would replace Cabernet Sauvignon with another cultivar, as Cabernet Sauvignon is a relatively hardy red wine grape cultivar, and can handle significant amounts of water stress; it is more resistant than cultivars such as Merlot and Shiraz. It was also argued that bearing cultivar should be selected based on market demand, and since Cabernet Sauvignon is a popular cultivar, it is not likely to be replaced with other cultivars. It was noted however that different rootstock could be selected, such as one of the new hybrid rootstock like M4, which is said to be drought resistant but can also handle wet conditions.

The next major component of the findings was formed around the issue of yield, and how it has been impacted by droughts. Droughts are generally associated with a decline in yield, however as seen in the findings, this is not always the case. This is why it is important to examine each winery in isolation. This subsection of the findings incorporated all thirteen respondents' answers, as each one was unique and site-specific. For example, during the drought which occurred between 2015 and 2019, wineries C and G experienced an overall increase

in yield, and wineries E and F experienced yields that remained fairly constant. The remaining nine wineries experienced a noticeable decrease in yields, of between 5% - 73.32%, for the period. The Greater Simonsberg route handled the drought best in terms of yield, as three out of the four wineries experienced a flat or even an increasing yield trend during this period. The findings also show that winery H experienced the largest decline in yield, of 73.32% between 2014 and 2015, however the average decline in yield for Cabernet Sauvignon for these nine farms was around 30%. Certain of the respondents mentioned that their winery experienced a decline in both yields as well as juice volume, which meant that the volume of wine that they could potentially make also declined. This translated into an impact on future potential income unless the price increased by the same extent by which the juice volume decreased.

Even though nine out of thirteen wineries experienced a decline in yield, as well as a decline in juice volume, certain positives aspects can be extracted from this situation. The findings showed that there is a clear relationship between the grape yield and grape quality, in that a smaller yield often is associated with higher quality grapes, up to a certain extent. It was also noted that to produce good quality grapes, yields needs to be slightly limited, so that the vine's energy is not divided across a large number of bunches. Rather each bunch of grapes can receive a sufficient amount of nutrients in order to develop properly, which will allow optimal grape quality to be achieved. This being said, there is a fine balance between producing a large enough yield to break even, but at the same time limit yield in order to achieve optimal quality. Each vine is unique, and will have its optimal bearing capacity, and therefore achieve optimal quality. It is vital that vines are managed according to their bearing capacity.

Throughout this study, it has been argued that the concept of grape quality remains subjective, although certain parameters are used to try and ascertain grape quality. The finding illustrates that there are a few key parameters which the respondents mentioned could be used to gauge the overall quality of Cabernet Sauvignon grapes. These main parameters were as follows: berry size, bunch size, distribution of berries in a bunch, skin to pulp ratio, sugar ratios colouring, flavours, and the overall health of the grape, which was associated with fewer rotten grapes. Many of these parameters are also interconnected, for example, smaller berries are associated with a higher skin to pulp ratio which could potentially mean more intense flavour concentration for the grapes. Certain of these parameters can be determined by either the grapes' visual appearance or taste, but others of them can more accurately be determined through tests that take place in labs. For example, the visual appearance can be used to indicate the overall colouring of grapes, but the more accurate way to determine the colouring is by sending samples to labs, which can measure the total anthocyanins pigment in grapes. These parameters can be useful in determining the overall grape quality in a particular season, however these parameters can only be used as guidelines to assess grape quality, because ultimately grape quality will always be subjective. It can be concluded that the linking of value to quality was a complex issue and also a highly subjective one. As such, more research on this topic is required to see if a more comprehensive response can be attained.

The majority of the wineries used for this study did not buy or sell any of their Cabernet Sauvignon grapes, and all the grapes harvested went straight into the production of wine at the winery; it can therefore be argued

that they did not use price as a direct method of measuring grape quality. It was also made clear that the term quality is ultimately subjective, and therefore a change in quality has been argued to have a smaller impact on price compared to a change in yield, nevertheless, it can be argued that the production of consistent high-quality grapes would put upward pressure on the price of grapes.

The findings indicated that there were many different viewpoints regarding the parameters which could be utilized to quantify grape quality. Each respondent had a slightly different outlook in terms of these parameters, however there were certain overlapping thoughts. Smaller berries for example are more desirable, and are associated with higher quality grapes, as they tend to have a higher skin to pulp ratio as well as more concentrated flavours. This is beneficial as many of these factors will be carried across into the wines produced from these grapes. There was also the expressed view that as there are many different factors that make up the overall quality, certain parameters can be desirable while other parameters are not, which makes it much harder to determine if the overall quality has improved.

It was clear to see that there were many different viewpoints on how the 2015-2019 drought had impacted the Cabernet Sauvignon grape quality at the various wineries. All respondents said that the drought has caused the size of the berries to decrease, however the impact that this had on quality was not unanimous, as certain of the respondents felt this improved grape quality. Others felt however that in specific years, the size of the grapes was too small, which caused the berries to overripen very easily and led to jammy characteristics; these respondents associated this with a lower grape quality. Several of the respondents said there had been a notable increase in Cabernet Sauvignon grape quality during the drought period, whereas other respondents noted that there has been a significant decrease in the grape quality. The balance of the respondents argued that it was difficult to say whether overall grape quality improved or not. It can be seen therefore that there is no single answer as to whether or not Cabernet Sauvignon grape quality improved during the drought.

The respondents that said that the grape quality had improved had common stances in terms of which parameters had improved during the drought, and what was responsible for the perceived improvement in grape quality. The first parameter to have improved during the drought was that of berry size. During the drought, it was argued that the berry size decreased, which had a knock-on effect; it increased the skin to pulp ratio, in addition to causing more concentrated and robust flavours. The smaller berries also meant that the berries were loosely distributed throughout the bunches, which allowed airflow between the grape. This made it more difficult for water to collect between grapes, and reduced the chance of rot and fungi, and increased the overall health of the grapes. Loosely distributed berries also increased the amount of sunlight that could penetrate the bunches, which tends to cause more consistent ripening, and improves the overall colouring. Colouring was another parameter that was said to have improved during the drought period, which is beneficial in red wines including the like of Cabernet Sauvignon. The respondents that said grape quality had decreased observed that the drought has caused a significant increase in leafroll symptoms, which restricted grapes from fully ripening. Another problematic parameter was the sugar ratio, as the drought increased the concentration of fructose which led to problematic fermentations during the winemaking process.

In order to answer the question “can the decline in Cabernet Sauvignon grape yield caused by droughts be counterbalanced by an increase in grape quality during the same period in the Stellenbosch region?”, it is important to compare the change in yield against the change in the grape quality, in addition to taking the respondents' opinions into account. The findings showed that three of the thirteen respondents said that a decline in Cabernet Sauvignon grape yields caused by droughts can be counterbalanced by an increase in grape quality. Two of these respondents however mentioned that this only occurred in certain years of the drought, for example 2015 and 2017. Respondents three and seven said that both grape quality and yield increased to a larger extent during the 2015-2019 drought. The remaining eight respondents argued that the decline in Cabernet Sauvignon grape yield caused by droughts was not counterbalanced by an increase in grape quality. The main reasoning behind this was because either they felt that grape quality did not increase, or said that even though the grape quality increased, it was not able to counteract the effect of the decline in yield, as this is said to have had a larger negative impact on future potential income compared to the increase in grape quality. It can, therefore, be concluded that there is no definitive answer to whether or not the decline in Cabernet Sauvignon grape yield caused by droughts can be counterbalanced by an increase in grape quality during the same period in the Stellenbosch region.

5.3 Recommendations

The study recognized that the primary data was gathered through either self-administrative questionnaires, or semi-structured personal interviews with viticulturists, winemakers, harvest interns, and farm managers at the various wineries. It soon became clear however that getting in contact with these respondents would not be an easy task as they are very busy, especially from January till April. This is due to the harvest coupled with the restrictions put in place by COVID-19. This made it difficult to gather data for this study. The study therefore can recommend that data collection needs to occurs well in advance to give the writer the chance to collect sufficient data, as well as schedule follow-up sessions, to get respondents to elaborate on certain aspects.

One limitation that occurred in this study was that of a relatively small sample size, which resulted in a limited quantity of data available for analysis. It can therefore be recommended that a larger sample size including respondents from farms that buy and sell Cabernet Sauvignon wine grapes as this would be beneficial to the study, as it will bolster the findings, as it could indicate more insight into how quality impacts the economic valuation of wine grapes during droughts as well as provide further practices and techniques that viticulturists and farm managers could implement to mitigate the negative impacts of the drought on vines, as well as limit the decline in yield of Cabernet Sauvignon.

The study revealed that there is a wide array of different factors and practices that can influence both grape quality and yield. It was also clear that the impact of the drought is also influenced by these different factors. Another constraining factor is that the geographic location for this study was limited to only the Stellenbosch region. It can therefore be recommended that cross-regional studies could be incorporated, to establish how the droughts have impacted different regions in the Western Cape, and to see how the region of Stellenbosch has handled the impact of droughts compared to other regions. This will also indicate other practices that could

be useful in mitigating the negative impact of droughts, as well as optimising both grape quality and yield during drought periods.

The issue of subjectivity arises throughout this study, however it was made clear that proxy measures, in the form of certain parameters such as berry size, sugar ratios and grape colouring could be used to establish the grape quality. The study therefore further recommends that more extensive qualitative data surrounding these parameters should be collected, in order to get more precise indications of how grape quality is impacted by droughts. Other data collection methods, such as focus group studies could be used, as this would allow the author to gain multiple perspectives surrounding this topic in a quick and flexible manner.

The scope of this study revealed that further research is necessary to understand the relationship between quality and value, and how this is impacted by climate variations such as drought. The respondents of this study suggested that this is subjective. The subjectivity in this assessment is due to the fact that there are numerous variables linked to value and quality. Therefore, in order to break down the complexity of this relationship, it can be recommended that more research is required around the linkage between the economic value and quality of Cabernet Sauvignon wine grapes and the impact of climatic Variations such as drought.

References

Accc. 2019. Wine grape market study. [online] Available at: https://www.accc.gov.au/focus-areas/market-studies/wine-grape-market-study [Accessed 19 Feb. 2020].

Adamu, G.K. and Aliyu, A.K., 2012. Determination of the influence of texture and organic matter on soil water holding capacity in and around Tomas Irrigation Scheme, Dambatta Local Government Kano State. Research Journal of Environmental and Earth Sciences, 4(12), pp.1038-1044.

AgriOrbit. 2018. Facts on the Western Cape drought - AgriOrbit. [online] Available at: https://www.agriorbit.com/facts-Western-Cape-drought/ [Accessed 6 Feb. 2020].

Alexander, L.V., 2016. Global observed long-term changes in temperature and precipitation extremes: a review of progress and limitations in IPCC assessments and beyond. Weather and Climate Extremes, 11, pp.4-16.

Ali, S., Rizwan, M., Qayyum, M.F., Ok, Y.S., Ibrahim, M., Riaz, M., Arif, M.S., Hafeez, F., Al-Wabel, M.I. and Shahzad, A.N., 2017. Biochar soil amendment on alleviation of drought and salt stress in plants: a critical review. Environmental Science and Pollution Research, 24(14), pp.12700-12712.

Allen, M. 2017. The sage encyclopedia of communication research methods (Vols. 1-4). Thousand Oaks, CA: SAGE Publications, Inc doi: 10.4135/9781483381411

Allen, R., Pereira, L., Raes, D. and Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements. Rome: FAO, pp.1-23.

Alston, M. and Kent, J., 2004. Social impacts of drought. Centre for Rural Social Research, Charles Sturt University, Wagga Wagga, NSW.

Alturria, L. and Solsona, J., 9th Conference AAAWE, May 26–30 2015. Mendoza, Argentina cost of production of grapes: identification of factors affecting the competitiveness and sustainability of companies (Mendoza, Argentina).

Amerine, M.A. and Thoukis, G., 1958. The glucose-fructose ratio of California grapes. Vitis, 1, pp.224-229.

Araujo, J.A., Abiodun, B.J. and Crespo, O., 2016. Impacts of drought on grape yields in Western Cape, South Africa. Theoretical and applied climatology, 123(1-2):117-130.

Araujo, J.A., Abiodun, B.J. and Crespo, O., 2016. Impacts of drought on grape yields in Western Cape, South Africa. Theoretical and applied climatology, 123(1-2), pp.117-130.

Ashenfelter, O., 2017. The hedonic approach to vineyard site selection: Adaptation to climate change and grape growing in emerging markets. Journal of Wine Economics, 12(1), pp.3-15.

Azevedo-Opazo, C., Ortega-Farías, S. and Moreno, Y., 2001, December. Effect of three levels of water application during post-setting and post-veraison over vegetative development, productivity and grape quality on cv. Cabernet Sauvignon. In International Symposium on Irrigation and Water Relations in Grapevine and Fruit Trees 646 (pp. 143-146).

Azevedo-Opazo, C., Ortega-Farías, S. and Moreno, Y., 2001. Effect of three levels of water application during post-setting and post-veraison over vegetative development, productivity and grape quality on cv. Cabernet Sauvignon. In International Symposium on Irrigation and Water Relations in Grapevine and Fruit Trees 646 (pp. 143-146).

Bahar, E. and Yasasin, A.S., 2010. The yield and berry quality under different soil tillage and clusters thinning treatments in grape (Vitis vinifera L.) cv. Cabernet-Sauvignon. African Journal of Agricultural Research, 5(21), pp.2986-2993.

Bak, N., 2004. Completing your thesis: A practical guide. Van Schaik Publishers.

Balint, G., 2012. Impact of different irrigation strategies on grapes and wine quality of four grapevine cultivars (Vitis sp.) in cool climate conditions. An investigation into the relationships among ABA, water status, grape cultivar, and wine quality.

Becker, R. 2018. Grapevines can survive with little water, but wine glasses could still go dry during droughts. [online] The Verge. Available at: https://www.theverge.com/2018/1/31/16956850/wine-grapes-vines-california-bordeaux-drought-science-viticulture [Accessed 5 Feb. 2020].

Boeije, H., 2009. Analysis in qualitative research. Sage publications., pp.155-180

Bois, B., Gavrilescu, C., Moriondo, M. and Jones, G.V., 2016. Wine growing regions global climate analysis. In Proceedings of the 11th International Terroir Congress, édité par Gregory Van Jones et Nicole Doran (pp. 9-14).

Bombrun, H. and Sumner, D.A., 2003. What determines the price of wine. AIC Issues Brief, 18, pp.1-6.

Bonnardot, V., Carey, V. and Rowswell, D. 2011. Observed climatic trends in Stellenbosch: Update and brief overview - Wineland Magazine. [online] Wineland Magazine. Available at: https://www.wineland.co.za/observed-climatic-trends-in-Stellenbosch-update-and-brief-overview/ [Accessed 10 Feb. 2020].

Boss, P.K., Davies, C. and Robinson, S.P., 1996. Anthocyanin composition and anthocyanin pathway gene expression in grapevine sports differing in berry skin colour. Australian Journal of Grape and Wine Research, 2(3), pp.163-170.

Botes, M.P., 2009. Evaluation of parameters to determine optimum ripeness in Cabernet Sauvignon grapes in relation to wine quality (Doctoral dissertation, Stellenbosch: University of Stellenbosch).

Bowman, S., 2018. Irrigation planning: Managing vineyard water security and efficiency. Australian and New Zealand Grapegrower and Winemaker (654), p.28.

Bredahl, M., 2020. Wines From Stellenbosch, A Wine Region In South Africa. [online] WorldsBestWines.eu. Available at: <https://worldsbestwines.eu/south-africa/stellenbosch/> [Accessed 11 November 2020].

Brown, S.C., 1981. Sugar accumulation in the developing grape berry (Doctoral dissertation). Sugar accumulation in the developing grape berry (Doctoral dissertation).

Bryman, A., 2006. Integrating quantitative and qualitative research: how is it done?. Qualitative research, 6(1), pp.97-113.

Burt, C., Mutziger, A., Allen, R. and Howell, T. 2005. Evaporation Research: Review and Interpretation. Journal of Irrigation and Drainage Engineering, 131(1), pp.37-58.

Busscher, W.J., Lipiec, J., Bauer, P.J. and Carter Jr, T.E., 2000. Improved root penetration of soil hard layers by a selected genotype. Communications in soil science and plant analysis, 31(19-20), pp.3089-3101.

Cabral, I., Nogueira, T., Carneiro, A. and Queiroz, J., 2018. Influence of irrigation on yield and quality of cv. Touriga Franca in the Douro Region. In E3S Web of Conferences (Vol. 50, p. 01014). EDP Sciences.

Camps, J.O. and Ramos, M.C., 2012. Grape harvest and yield responses to inter-annual changes in temperature and precipitation in an area of north-east Spain with a Mediterranean climate. International journal of biometeorology, 56(5):853-864.

Camps, J.O. and Ramos, M.C., 2012. Grape harvest and yield responses to inter-annual changes in temperature and precipitation in an area of north-east Spain with a Mediterranean climate. International journal of biometeorology, 56(5):853-864.

Cancler, C. 2012. The home preserving bible. New York: Alpha Books, pp.2-12.

Carew, R. and Florkowski, W.J., 2010. The importance of geographic wine appellations: hedonic pricing of burgundy wines in the British Columbia wine market. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 58(1), pp.93-108.

Carson, D., Gilmore, A., Perry, C., and Gronhaug, K. 2001. Qualitative Marketing Research. London: Sage.

Charters, S. and Pettigrew, S., 2007. The dimensions of wine quality. Food Quality and Preference, 18(7), pp.997-1007.

Chaves, M.M., Zarrouk, O., Francisco, R., Costa, J.M., Santos, T., Regalado, A.P., Rodrigues, M.L. and Lopes, C.M., 2010. Grapevine under deficit irrigation: hints from physiological and molecular data. *Annals of botany*, *105*(5), pp.661-676.

Chaves, M.M., Zarrouk, O., Francisco, R., Costa, J.M., Santos, T., Regalado, A.P., Rodrigues, M.L. and Lopes, C.M., 2010. Grapevine under deficit irrigation: hints from physiological and molecular data. Annals of botany, 105(5):661-676.

Chesworth, P.M., 1994. History of water use in the Sudan and Egypt. The Nile: Sharing a Scarce Resource. A Historical and Technical Review of Water Management and of Economic and Legal Issues, pp.65-80.

Cholette, S., Castaldi, R. and Fredrick, A., 2005, January. The globalization of the wine industry: Implications for old and new world producers. In *International Business and Economy Conference Proceedings*.

Çolak, Y.B. and Yazar, A., 2017. Evaluation of crop water stress index on Royal table grape variety under partial root drying and conventional deficit irrigation regimes in the Mediterranean Region. Scientia horticulturae, 224, pp.384-394.

Combris, P., Lecocq, S. and Visser, M., 1997. Estimation of a hedonic price equation for Bordeaux wine: does quality matter?. The Economic Journal, 107(441), pp.390-402.

Coombe, B.G. (1992) Research on development and ripening of the grape berry. American Journal of Enology and Viticulture 43, 101-110.

Coombe, B.G. and McCarthy, M.G. (2000) Dynamics of grape berry growth and physiology of ripening. Australian Journal of Grape and Wine Research 6, 131-135.

Coombe, B.G., 1986, August. Influence of temperature on composition and quality of grapes. In Symposium on Grapevine Canopy and Vigor Management, XXII IHC 206 (pp. 23-36).

Coombe, B.G., Dundon, R.J. and Short, A.W., 1980. Indices of sugar—acidity as ripeness criteria for winegrapes. Journal of the Science of Food and Agriculture, 31(5), pp.495-502.

Cooper, J.D., 2016. Soil water measurement: a practical handbook. John Wiley & Sons. PP 237-256

Creswell, J. and Clark, V. 2011. Designing and conducting mixed methods research. 2nd ed. Thousand Oaks: Sage.

Corsi, A. and Ashenfelter, O., 2019. Predicting Italian wine quality from weather data and expert ratings. Journal of Wine Economics, 14(3), pp.234-251.

Creswell, J., W. 2007. Research design. Qualitative and mixed methods approach. London: Sage.

Creswell, J.W., Clark, J., Gutmann, V., Hanson, W., Clark, V. and Creswell, J., 2008. An expanded typology for classifying mixed methods research into designs. The mixed-methods reader, pp.159-196.

Cross, R., Plantinga, A.J. and Stavins, R.N., 2011. What is the Value of Terroir?. American Economic Review, 101(3), pp.152-56.

Crossen, T. 1997. Venture into viticulture. 1st ed. victoria - Australia: Bolwarrah press, pp.80-104.

DAFF, 2018. Economic Review of the South African Agriculture 2017/18. [online] Available at: https://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Economic%20Review%202017%20-18.pdf. [Accessed 7 Feb. 2020].

Danaher, P.J., Wilson, I.W. and Davis, R.A., 2003. A comparison of online and offline consumer brand loyalty. Marketing Science, 22(4), pp.461-476.

Dangremond, S., 2019. The 10 Most Expensive Wines in the World. [online] Town & Country. Available at: https://www.townandcountrymag.com/leisure/drinks/g25839214/most-expensive-wine/ [Accessed 4 Feb. 2020].

Darling, G. 1999. Effect of Competition Policy on Wine Grape Growers, Paper 6 in Legal and Accounting Management Seminars, Wine Industry and the Law 1999 Seminar Series, LAAMS Publications, Sydney.

De villiers, f., Schmidt, a., theron, j. and talijaard, R.,1996. sub division of the Western Cape viticutural regions according to existing climatic criteria. Wynboer tegnies.

Department of Environmental Affairs, 2017. South Africa's 2nd Annual Climate Change Report. Pretoria: Department of Environmental Affairs

Dharmadhikari, M., 1994. Composition of grapes. Vineyard Vintage View Mo State Univ, 9(7/8), pp.3-8.

Di Genova, A., Almeida, A.M., Muñoz-Espinoza, C., Vizoso, P., Travisany, D., Moraga, C., Pinto, M., Hinrichsen, P., Orellana, A. and Maass, A., 2014. Whole genome comparison between table and wine grapes reveals a comprehensive catalog of structural variants. BMC plant biology, 14(1), p.7.

Doyle, L., Brady, A.M. and Byrne, G., 2009. An overview of mixed methods research. Journal of research in nursing, 14(2), pp.175-185.

Easton, s. (2010). Cool climate Australia : WineWisdom. [online] Winewisdom.com. Available at: http://www.winewisdom.com/articles/regional-profiles/cool-climate-australia/ [Accessed 4 Feb. 2020].

Edirisingha, P., 2012. Interpretivism and positivism (ontological and epistemological perspectives). Research Paradigms and Approaches.

Fao. 1990. Irrigation Water Management: Irrigation Methods. [online] Available at: http://www.fao.org/3/s8684e/s8684e07.htm#chapter%206.%20drip%20irrigation [Accessed 12 Feb. 2020].

Fao. 2001. Principles and practices of small - and medium - scale fruit juice processing. [online] Available at: http://www.fao.org/3/y2515e/y2515e13.htm [Accessed 14 Feb. 2020].

Fao. 2002. Crops and Drops. [online] Available at: http://www.fao.org/3/y3918e/y3918e10.htm [Accessed 12 Feb. 2020].

Fao. 2008. Commision (EC) No 1221/2008 of 5 December 2008. [online] Available at: http://www.fao.org/faolex/results/details/en/c/LEX-FAOC084578 [Accessed 14 Feb. 2020].

Ferreira, S.L. and Muller, R., 2013. Innovating the wine tourism product: Food-and-wine pairing in Stellenbosch wine routes. African Journal for Physical Health Education, Recreation and Dance, 19(Supplement 3), pp.72-85.

Ferreyra, R., Selles, G., Peralta, J., Burgos, L. and Valenzuela, J., 2002. Effects of restricted irrigation at different stages of development of Cabernet Sauvignon grapes on production and wine quality. Agricultura Tecnica, 62, pp.406-417

Fourie, S., 2018. Overview of the Western Cape water crisis, long term water challenges and responses.

Fraser, I., 2003. The role of contracts in wine grape supply coordination: an overview. Australasian Agribusiness Review, 11(1673-2016-136814).

Gafner J, and Schütz M., 1996 Impact of glucose–fructose-ratio on stuck fermentations: practical experiences to restart stuck fermentations. Vitic Enol Sci 51:214–21

Gibbs, G.R., 2018. Analysing qualitative data (Vol. 6). Sage.

Gil, P.M., Lobos, P., Durán, K., Olguín, J., Cea, D. and Schaffer, B., 2018. Partial root-zone drying irrigation, shading, or mulching effects on water savings, productivity and quality of 'Syrah'grapevines. Scientia Horticulturae, 240, pp.478-483.

Gil-Muñoz, R., Moreno-Olivares, J.D., Paladines-Quezada, D.F., Cebrían-Pérez, A. and Fernández-Fernández, J.I., 2018. High Anthocyanin Level of Grape Hybrids from Monastrell and Their Wines.

Gladstones, J., 1992. Viticulture and environment: Winetitles. Adelaide, Australia

Goldammer, T., 2018. The Grape Grower's Handbook: A Guide to Viticulture for Wine Production. Apex publishers.

Goussard, P.G., 2008. Grape cultivars for wine production in South Africa.

Groenendyk, D.G., Ferré, T.P., Thorp, K.R. and Rice, A.K., 2015. Hydrologic-process-based soil texture classifications for improved visualization of lands Cape function. PloS one, 10(6)

Hacke, U.G., Sperry, J.S., Ewers, B.E., Ellsworth, D.S., Schäfer, K.V.R. and Oren, R., 2000. Influence of soil porosity on water use in Pinus taeda. Oecologia, 124(4), pp.495-505.

Haughton, G. and Browett, J., 1995. Flexible Theory and Flexible Regulation: Collaboration and Competition in the McLaren Vale Wine Industry in South Australia, Environment and Planning A, Vol 27, pp 41-61.

Hargrave, M., 2019. Using Hedonic Pricing To Determine The Factors Impacting Home Prices. [online] Investopedia. Available at: <https://www.investopedia.com/terms/h/hedonicpricing.asp> [Accessed 12 November 2020].

He, F., Liang, N.N., Mu, L., Pan, Q.H., Wang, J., Reeves, M.J. and Duan, C.Q., 2012. Anthocyanins and their variation in red wines I. Monomeric anthocyanins and their color expression. Molecules, 17(2), pp.1571-1601

Heyns, L. 2016. MANAGEMENT OF GRAPEVINES DURING DROUGHT PERIODS. Practical Guidelines. Institute for Grape and Wine Sciences. South Africa: Stellenbosch.

Homaee, M., Feddes, R.A. and Dirksen, C., 2002. Simulation of root water uptake: III. Non-uniform transient combined salinity and water stress. Agricultural water management, 57(2), pp.127-144.

Hopfer, H. and Heymann, H., 2014. Judging wine quality: Do we need experts, consumers or trained panelists?. Food Quality and Preference, 32, pp.221-233.

Hsieh, H.F. and Shannon, S.E., 2005. Three approaches to qualitative content analysis. Qualitative health research, 15(9), pp.1277-1288.

Ingels, C.A., Scow, K.M., Whisson, D.A. and Drenovsky, R.E., 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. American journal of enology and viticulture, 56(1):19-29.

Intrigliolo, D.S., Lizama, V., García-Esparza, M.J., Abrisqueta, I. and Álvarez, I., 2016. Effects of post-veraison irrigation regime on Cabernet Sauvignon grapevines in Valencia, Spain: yield and grape composition. Agricultural Water Management, 170, pp.110-119.

IPCC, 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation[Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 555-564.

Irrico. 2020. Sub-Surface Drip Irrigation. [online] Available at: https://www.irrico.net/sub-surface-drip-irrigation/ [Accessed 13 Feb. 2020].

ISO 9000, 2005. Quality management systems–Fundamentals and vocabulary.

Jackson, D.I. and Lombard, P.B., 1993. Environmental and management practices affecting grape composition and wine quality-a review. American Journal of Enology and Viticulture, 44(4), pp.409-430.

Johnston PJ 2009 (unpublished). Climate change risk model for tablegrape growers, prepared for the Fynbos Foundation, Cape Town, South Africa.

Jones, G.V. and Davis, R.E. 2000. Climate Influences on Grapevine Phenology, Grape Composition, and Wine Production and Quality for Bordeaux, France. American Journal of Enology and Viticulture. [Electronic]. Available: http://www.ajevonline.org/content/ajev/51/3/249.full.pdf [2018, April 16].

Jones, G.V., 2007, July. Climate change and the global wine industry. In Proceedings of the 13 th Annual Australian Wine Industry Technical Conference, Adelaide. http://www. sou. edu/Geography/JONES/AWITC% 20GJones. pdf.

Jones, G.V., 2010. Climate, grapes, and wine: structure and suitability in a changing climate. In XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on the 931 (pp. 19-28).

Jones, G.V., 2015. Climate grapes and wine: Terroir and the importance of climate to winegrape production. GuildSomm Petaluma CA.

Jones, G.V., M. A. White, O. R. Cooper, and K. Storchmann. 2005. Climate Change and Global Wine Quality. Climatic Change, 73(3): 319-343.

Jordão, A.M., Vilela, A. and Cosme, F., 2015. From sugar of grape to alcohol of wine: Sensorial impact of alcohol in wine. Beverages, 1(4), pp.292-310.

Kader, A.A. 1999. Fruit Maturity, Ripening, and Quality relationships. Acta Hortic. 485, 203-208. https://doi.org/10.17660/ActaHortic.1999.485.27

Kaiser, R.M., Cavagnaro, J.B. and Rios, M., 2001, December. Response of Argentinian and European Cultivars of Vitis vinifera L. to Water Stress: I. Vegetative Growth. In International Symposium on Irrigation and Water Relations in Grapevine and Fruit Trees 646 (pp. 41-46).

Kalaba, M. 2019. How droughts will affect South Africa's broader economy. [online] The Conversation. Available at: http://theconversation.com/how-droughts-will-affect-South-africas-broader-economy-111378 [Accessed 6 Feb. 2020].

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., Van Der Putten, W.H. and Bardgett, R.D., 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil.

Keller, M., 2010. Managing grapevines to optimise fruit development in a challenging environment: a climate change primer for viticulturists. Australian Journal of Grape and Wine Research, 16, 56-69.

Kennedy, J., 2002. Understanding grape berry development. Practical winery & vineyard, 4, pp.1-5.

Kenton, W., 2019. Understanding Intermediate Goods. [online] Investopedia. Available at: <https://www.investopedia.com/terms/i/intermediate-good.asp#:~:text=An%20intermediate%20good%20is%20a,to%20manufacture%20other%20food%20products.> [Accessed 12 November 2020].

Kothari, C. 2004. Research methodology. 1st ed. New Delhi: New Age International (P) Ltd., pp.1-12.

Lacalle, D., 2020. The Importance of Profit and Sound Financing in Socially Responsible Investment. JBAFP, 2(2), pp.0-0.

Lambert J, Anderson M, Wolpert J. 2008. Vineyard nutrient needs vary with rootstocks and soils. Calif Agr 62(4):202-207. https://doi.org/10.3733/ca.v062n04p202.

Landon, S. and Smith, C.E., 1998. Quality expectations, reputation, and price. Southern Economic Journal (628-647).

Lanyon, D.M., Hansen, D. and Cass, A., 2004. The effect of soil properties on vine performance. Black Mountain: CSIRO Land and Water.

Laxton, D. 2004. 'Chapter 2: The research process'. In: Coldwell, D. and Herbst, F. J. eds. Business research. Cape Town: JUTA Academic. 25-91.

Le Roux, C., 2012. An assessment of the role of corporate brand identity in corporate brand image formation (Doctoral dissertation).

Le Roux, E.G., 1974. A climate classification for the South Western Cape viticultural areas (Doctoral dissertation, MSc thesis, Stellenbosch University, Stellenbosch, South Africa).

Lindemann, B., 1996. Taste reception. Physiological reviews, 76(3), pp.719-766

Lock, P., Mounter, S., Fleming, E. and Moss, J., 2019. Wineries and wine quality: The influence of location and archetype in the Hunter Valley region in Australia. Wine Economics and Policy, 8(2), pp.180-190.

Lockshin, L. and Corsi, A.M., 2012. Consumer behaviour for wine 2.0: A review since 2003 and future directions. Wine Economics and Policy, 1(1), pp.2-23.

Lutzeyer, S., 2008. Estimating hedonic prices for Stellenbosch wine. University of Stellenbosch and Bureau for Economic Research.

Manske, M. and Cordua, G., 2005. Understanding the sommelier effect. International journal of contemporary hospitality management.

Maps-Southafrica.com,2020. Weather map South Africa - South Africa weather map (Southern Africa - Africa). [online] Available at: https://maps-Southafrica.com/weather-map-South-africa [Accessed 4 Feb. 2020].

Matthews, M.A. and Vuzzo, N. 2007. Berry Size and Yield Paradigms on Grapes and Wines Quality. [Online]. Available: http://matthews.ucdavis.edu/publications-1/Matthews%20-%20Berry%20Size%20and%20Yield%20Paradigms%20on%20Grape.pdf [2018, April 17].

Mercurio, M.D., Dambergs, R.G., Cozzolino, D., Herderich, M.J. and Smith, P.A., 2010. Relationship between red wine grades and phenolics. 1. Tannin and total phenolics concentrations. Journal of agricultural and food chemistry, 58(23), pp.12313-12319.

Midgley, G.F., Chapman, R.A. and Hewitson, B., 2005. A status quo, vulnerability and adaptation assessment of the physical and socio-economic effects of climate change in the Western Cape.

Mirás-Avalos, J.M. and Intrigliolo, D.S. 2017. Grape Composition under Abiotic Constrains: Water Stress and Salinity. Frontiers in Plant Science. [Electronic]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5447678/ [2018, April 16].

Mitcham, B., Cantwell, M. and Kader, A. 1996. Division of Agiculture and Natural Resources. [Online]. Available: http://ucanr.edu/datastoreFiles/608-295.pdf [2018, April 14].

Moeys, J., 2018. The soil texture wizard: R functions for plotting, classifying, transforming and exploring soil texture data. CRAN. R-Project.

Molitor, D., Rothmeier, M., Behr, M., Fischer, S., Hoffmann, L. and Evers, D., 2011. Crop cultural and chemical methods to control grey mould on grapes. Vitis, 50(2), pp.81-87.

Moreda, G.P., Ruiz-Altisent, M., y Tecnologías, L.D.P.F. and en Agro-Alimentación, A., 2011. Quality of agricultural products in relationto physical.

Morris, J.R. 1998. Factors influencing grape juice quality. Hort Technology. [Electronic], 8(4). Available: http://horttech.ashspublications.org/content/8/4/471.full.pdf [2018, April 14].

Myburgh PA, Cass A and Clingeleffer PR 1996. Root systems and soils in Australian vineyards and orchards - an assessment. 1996 Barossa Valley Rotary Foundation Fellowship Report. (CRC Soil & Land Management)

Myburgh, P., 2018. Handbook for irrigation of wine grapes in South Africa. 1st ed. Pretoria: Agricutural Research Council, pp.14-28.

Myburgh, P.A 2006. Irrigation management with particular reference to wine quality - A brief overview of South African research - Wineland Magazine. [online] Wineland Magazine. Available at: https://www.wineland.co.za/irrigation-management-with-particular-reference-to-wine-quality-a-brief-overview-of-South-african-research/ [Accessed 25 Feb. 2020].

Myburgh, P.A., 2009. Optimal irrigation strategies for the Little Karoo. Presentation at Vinpro information day, 16 April 2009, Calitzdorp

Myburgh, P.A., 2015. A lysimeter study to determine input values for a simple parametric soil evaporation model for vineyards. S. Afr. J. Plant Soil, 32, pp.1-8.

Norrie, J., Branson, T. and Keathley, P.E., 2001. Marine plant extracts impact on grape yield and quality. In International Symposium on Foliar Nutrition of Perennial Fruit Plants 594 (pp. 315-319).

NSW Agriculture 2004. 'Irrigating grapevines with limited water supplies.' Agricultural Note. ISBN 0 7347 1574 9.

Nuzzo, V. and Matthews, M.A., 2005, September. Berry Size and Yield Paradigms on Grapes and Wines Quality. In International Workshop on Advances in Grapevine and Wine Research 754 (pp. 423-436).

Olson, N.C., Gulliver, J.S., Nieber, J.L. and Kayhanian, M., 2013. Remediation to improve infiltration into compact soils. Journal of environmental management, 117, pp.85-95.

Pham, L.T.M., 2018. A Review of Key Paradigms: Positivism. Interpretivism & Critical Inquiry, School of Education, The University of Adelaide.

Pienaar, L., & Boonzaaier, J. 2018. Drought Policy Brief Western Cape Agriculture. Bureau for Food and Agricultural Policy (BFAP). South Africa: Western Cape.

Platter's. 2020. Platter's - About. [online] Available at: https://www.wineonaplatter.com/about [Accessed 18 Feb. 2020].

Poni, S., Gatti, M., Palliotti, A., Dai, Z., Duchêne, E., Truong, T.T., Ferrara, G., Matarrese, A.M.S., Gallotta, A., Bellincontro, A. and Mencarelli, F., 2018. Grapevine quality: A multiple choice issue. Scientia horticulturae, 234, pp.445-462.

Potop V,F 2011 Evolution of drought severity and its impact on corn in the Republic of Moldova. Theor Appl Climatol 105(3–4):469–483

Reynolds, A.G. and Naylor, A.P., 1994. Pinot Noir' and Riesling' Grapevines Respond to Water Stress Duration and Soil Water-holding Capacity. HortScience, 29(12), pp.1505-1510.

Reynolds, A.G., 2010. Viticultural and vineyard management practices and their effects on grape and wine quality. In Managing wine quality (pp. 365-444). Woodhead Publishing.

Ritchie, J.T., 1998. Soil water balance and plant water stress. In Understanding options for agricultural production (pp. 41-54). Springer, Dordrecht.

Roby, G. and Matthews, M.A. 2004. Relative proportions of seed, skin and flesh, in ripe berries from Cabernet Sauvignon grapevines grown in a vineyard either well irrigated or under water deficit. Australian J. Grape and Wine Research 10: 74-82.

Romero, P., Fernández-Fernández, J.I. and Martinez-Cutillas, A. 2010. Physiological thresholds for efficient regulated deficit-irrigation management in winegrapes grown under semiarid conditions. American Journal of Enology and Viticulture, 61(3):300-312.

Romero, P., Fernández-Fernández, J.I., Gil-Munoz, R. and Botia, P., 2016. Vigour-yield-quality relationships in long-term deficit irrigated winegrapes grown under semiarid conditions. Theoretical and Experimental Plant Physiology, 28(1), pp.23-51.

Ross, C.F. and Weller, K., 2008. Effect of serving temperature on the sensory attributes of red and white wines. Journal of sensory studies, 23(3), pp.398-416.

Salon, J.L., Méndez, J.V., Chirivella, C. and Castel, J.R., 2001. IRRIGATION AND WINE QUALITY OF VITIS VINIFERA CV. BOBAL IN REQUENA. SPAIN. In International Symposium on Irrigation and Water Relations in Grapevine and Fruit Trees 646 (pp. 167-174).

Santarosa. 2014. Sensory Evaluation: Introduction to Enology. [online] Available at: http://www.santarosa.edu/~jhenderson/Sensory.pdf [Accessed 18 Feb. 2020].

Sawi. 2013. Recognised wine competitions. [online] Available at: http://www.sawineindex.com/page/list-of-wine-competitions/ [Accessed 18 Feb. 2020].

SAWIS. 2005. 2005 Statistics. [Online]. Available: http://www.SAWIS.co.za/info/download/ Book_2005_statistics_year_ english_final.pdf [2018, May 13].

SAWIS. 2015. Macroeconomic Impact of the Wine Industry on the South African Economy (also with reference to the Impacts on the Western Cape). [online] Available at: http://www.SAWIS.co.za/info/download/Macro economic_impact_study_Final_Report_Version_4_30Jan2015.pdf [Accessed 26 Feb. 2020].

SAWIS. 2016. 2016 Statistics. [Online]. Available: http://www.SAWIS.co.za/info/download/ Book_2016_statistics_year_english_final.pdf [2018, May 10].

SAWIS. 2018. Annual Publication | SAWIS. [online] Available at: <http://www.SAWIS.co.za/ info/annualpublication.php> [Accessed 9 March 2020].

SAWIS. 2018. *Annual Publication | SAWIS*. [online] Available at: http://www.SAWIS.co.za/info/annualpublication.php [Accessed 4 Mar. 2020].

SAWIS. 2020. [online] Available at: <http://www.sawis.co.za/info/download/ Book_2019_statistics_english_web_final.pdf> [Accessed 9 November 2020].

SAWIS. 2020. [online] Available at: <http://www.sawis.co.za/dictionary/dictionary.php?view=7350> [Accessed 26 May 2020].

Scales, W., Croser, B. and Freebairn, J. 1995 Winegrape and Wine Industry in Australia: A Report by the Committee of Inquiry into the Winegrape and Wine Industry, Australian Government Publishing Service, Canberra.

Schamel, G., 2000. Individual and Collective Repuatation Indicators of Wine Quality.

Schultz, H.R., 2000. Climate change and viticulture: A European perspective on climatology, carbon dioxide and UV-B effects. Australian Journal of Grape and Wine Research 6, 2-12.

Segade, S.R., Rolle, L., Gerbi, V. and Orriols, I., 2008. Phenolic ripeness assessment of grape skin by texture analysis. Journal of Food Composition and Analysis, 21(8), pp.644-649.

Serra, I., Strever, A., Myburgh, P.A. and Deloire, A., 2014. the interaction between rootstocks and cultivars (Vitis vinifera L.) to enhance drought tolerance in grapevine. Australian Journal of Grape and Wine Research, 20(1), pp.1-14.

Storchmann, K., 2012. Wine economics. Journal of Wine Economics, 7(1), pp.1-33

Tashakkori, A. and Creswell, J.W., 2007. The new era of mixed methods.

Tomsik, P., Stojanova, H., Sedlo, J. and Vajcnerova, I., 2016. Factors of profitability of the grapes production. Agricultural Economics, 62(6), pp.292-297.

Tonietto, J. and Carbonneau, A. 2004. A multicriteria climatic classification system for grape-growing regions worldwide. Agric. Forest Meteorol. 124:81-97.

UNICEF, 2011. Exploring the Impact of Climate Change on Children in South Africa.Pretoria: UNICEF South Africa

Vallone, R.C., Nijensohn, L., Cavagnaro, J.B., Merlo, E.E. and Maffei, J.A., 2004. Validation of a simple biological indicator of plant water status to determine irrigation timing of grapevines Vitis vinifera, L. Acta horticulturae.

Van Leeuwen, C. and Darriet, P., 2016. The impact of climate change on viticulture and wine quality. Journal of Wine Economics, 11(1), pp.150-167.

van Leeuwen, C., Roby, J.P. and de Rességuier, L., 2018. Soil-related terroir factors: A review. Oeno one, 52(2), pp.173-188.

Van Zyl, J.L., 1984. Interrelationships among soil water regime, irrigation and water stress in the grapevine (Vitis vinifera L.) (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Viljoen, F. 2018. What's happening in the vineyard. [Online]. Available: http://vinpro.co.za/wp-content/uploads/2018/01/Whats-happening-in-the-vineyard-Francios-Viljoen-.pdf [2018, May 10].

Vinpro. 2019. The 2018 vintage: A watershed year for the South African wine industry? [online] Available at: https://www.namc.co.za/wp-content/uploads/2019/05/Wine-grape-production-cost-2018-harvest.pdf. [Accessed 12 Feb. 2020].

Wani, R.A, Sheema, S., Dar, N.A., Angchuk, S. and Parray, G.A. 2013. Irrigation Regimes Effecting Drought Tolerance Of Grape Rootstocks Under Cold Arid Conditions. International Journal Of Scientific & Technology Research. [Electronic]. Available: https://pdfs.semanticscholar.org/4db9/e33e00fd8155c6e374a6d069a7bcc71bd4f1.pdf [2018, April 21].

Webber, M. and Labaste, P., 2011. Value chain analysis in agribusiness and Agricuture in sub Saharan Africa.[online] worldbank. Available at: http://siteresources.worldbank.org/INTARD/Resources/Building_ Competitiveness_in_Africa_Ag.pdf [Accessed 14 Feb. 2020]

Wheeler, S.J., Black, A.S. and Pickering, G.J., 2005. Vineyard floor management improves wine quality in highly vigorous Vitis vinifera'Cabernet Sauvignon'in New Zealand.

Wheeler, S.J., Black, A.S. and Pickering, G.J., 2005. Vineyard floor management improves wine quality in highly vigorous Vitis vinifera'Cabernet Sauvignon'in New Zealand.

Wilhite, D. 2000. Drought. 1st ed. London: Routledge, pp. 3–18.

Wine-Searcher. 2020. Most Expensive South African Wine. [online] Available at: <https://www.wine-searcher.com/regions-south+africa?tab_F=mostexpensive> [Accessed 11 November 2020].

Wine Searcher. 2020. The World's Most-Planted Varieties: Winners & Losers | Wine-Searcher News & Features. [online] Available at: https://www.wine-searcher.com/m/2014/01/the-worlds-most-planted-varieties-winners-losers [Accessed 13 Feb. 2020].

Winkler, A.J., Cook, J.A., Kliewer, W.M. and Lider, L.A., 1974. General Viticulture. Univ. Calif. Press. Berkeley, Los Angeles, London

Wolski, P. 2018. How severe is the drought? An analysis of the latest data. [online] GroundUp News. Available at: https://www.groundup.org.za/article/how-severe-drought-detailed-look-data/ [Accessed 7 Feb. 2020].

Wosa. 2020. Wines of South Africa - Red-wine varieties. [online] Available at: https://www.wosa.co.za/The-Industry/Varieties-and-Styles/Red-Wine-Varieties/ [Accessed 13 Feb. 2020].

WWF. 2018. Agricultural water file: Farming for a drier future. [online] Available at: https://www.wwf.org.za/water/?25441/Agricultural-water-file-Farming-for-a-drier-future [Accessed 12 Feb. 2020].

Xie, B., Brewer, M.B., Hayes, B.K., McDonald, R.I. and Newell, B.R., 2019. Predicting climate change risk perception and willingness to act. Journal of Environmental Psychology, 65, p.101331.

Yıldırım, H.K., 2013. Assessing wines based on total phenols, phenolic acids and chemometrics by multivariate analyses. African Journal of Biotechnology, 12(22).

Zikmund, W., Babin, B., Carr, J. & Griffin, M. 2010.Business Research Methods. Australia: South-Western, Cengage Learning

Zikmund, w., Babin, B., Carr, j. and Griffin, m. 2013. Business Research Methods. 9th ed. Cengage Learning, pp.85-106.

Annexure A

Ethical Clearance Approval Letter

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

NOTICE OF APPROVAL

REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

1 August 2019

Project number: 10305

Project Title: An Analysis on Whether the Decrease in Quantity in Wine grape Production will be counterbalanced by the Increase in Quality of Wine Grapes during Drought Periods in the Stellenbosch Region

Dear Mr Lennox Freemantle

Your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on 15 July 2019 was reviewed and approved by the REC: Humanities.

Please note the following for your approved submission:

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
1 August 2019	31 July 2022

GENERAL COMMENTS:

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number (10305) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Budget	travel costs for the interviews	15/05/2019	1
Research Protocol/Proposal	Agricultural Economics Proposal	16/05/2019	1
Data collection tool	Overview questions	21/05/2019	1
Request for permission	Thelema permission letter	26/06/2019	1
Request for permission	Beyerskloof permission letter	26/06/2019	1
Request for permission	simonsig permission letter	26/06/2019	1
Request for permission	Villiera permission letter	26/06/2019	1
Request for permission	Neil Ellis permission letter	26/06/2019	1
Request for permission	Camberly permission letter	26/06/2019	1
Request for permission	Long Ridge permission letter	27/06/2019	1
Informed Consent Form	L. Freemantle Written Consent	02/07/2019	2

Default	DESC_REC_RESPONSE LETTER	02/07/2019	1

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.
The Research Ethics Committee: Humanities complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

Annexure B

Example of the Letter for Institutional permission issues to the different wineries (A-M)

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

REQUEST LETTER FOR INSTITUTIONAL PERMISSION

WINE ESTATE NAME:

WINE ESTATE CONTACT PERSON:

WINE ESTATE CONTACT NUMBER:

WINE ESTATE EMAIL ADDRESS:

TITLE OF RESEARCH PROJECT: Whether the Decrease in Quantity in Wine grape Production will be counterbalanced by the Increase in Quality of Wine Grapes during Drought Periods in the Stellenbosch Region

RESEARCHER: Lennox Freemantle

DEPT NAME & ADDRESS: Department of AgriSciences, Stellenbosch University

CONTACT NUMBER: 0768587058

EMAIL ADDRESS: 19006896@sun.ac.za

Dear Wine Estate,

Kindly note that I am an MSc AgriSciences Economics student at the Department of AgriSciences at Stellenbosch University, and I would appreciate your assistance with one facet of my research project.

Please take some time to read the information presented in the following five points, which will explain the purpose of this letter as well as the purpose of my research project, and then feel free to contact me if you require any additional information.

1. **A short introduction to the project:**

   You have been approached as a possible participant to explore how drought periods in your opinion affected the wine grapes quality and quality compared to normal periods. The data collected will be used to analysis whether the Decrease in Quantity in Wine grape Production can possibly counterbalance the Increase in Quality of Wine Grapes focusing on cabernet sauvignon grapes in order to see how water management can be used to optimize both quality and quantity.

2. **The purpose of the project:**

   Is to look at what impact droughts have on the quality and quantity of wine grapes especially cabernet sauvignon grapes since climate change has impacted the rain patterns. This study will allow grape growers and wine estates to the ability to see how grape quality and quantity is affected during drier years in the Stellenbosch region and show them what changes they can expect during drier years as well as possible ways around these impacts to optimize both grape quality and quantity during drought periods.

3. **Your assistance would be appreciated in the following regard:**

   If your estate agrees to take part in this study, your estate will be asked a range of questions surrounding the quality and quantity of the grapes on the estate and the personal opinion of you as winemaker/harvest intern/owner – anonymity will be assured of names to ensure no reputational risks – on how droughts affect quality and quantity of grapes in general and, to what factors indicated quality in wine grapes as well as possible methods to measure quality and finally. The questions will ask your opinion on what steps can be taken to ensure you optimize both quality and quantity during drier years. An online questionnaire will be distributed to the relevant stakeholders which they can fill in anonymously through a google document. There may also be the request for interviews with relevant stakeholders – which the estate may feel free to decline – which will serve as a supporting source but not solely dependent on for the study to continue. The name of the wine estate will, however, appear in the research study.

4. **Confidentiality:**

   Any information you share with me during this study and that could possibly identify relevant stakeholders as a participant will be protected. This will be done by omitting any reference of specific individual's narratives and information shared. Data collected will be stored on my

university network space and Google drive both of which are password-protected locations which reduces the risk of information being stolen or misplaced. The name of your Estate/Farm if applicable however will be included in the study and any specific iconic figures relevant to the estate/farm will be included in the study only with your consent. Your estate/farm and any parties interviewed do have the option to opt-out of their information being shared if they wish. There is the possibility of the information collected for this study to be used for future publications and used for other academic or organizational purposes in the future such as Ph.D. studies. If permission of access is granted to information of the wine estate being included in the study, please state in your response letter that you are aware that your estates' name will not be anonymous.

5. **The timeframe of the research project**

   This research study will be concluded by the end of 2020. All correspondence with the wine estate can be conducted over email.

If you have any further questions or concerns about the research, please feel free to contact me via email (19006896@sun.ac.za) or telephonically (0768587058). Alternatively, feel free to contact my supervisor, Mr. Heinrich Gerwel, via email (hgerwel@sun.ac.za).

Thank you in advance for your assistance in this regard.

Kind regards,
Lennox Freemantle
Principal Investigator

Annexure C

Example of the Consent form issued to the different respondents (1-16)

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Dear **Participan**t,

This research study is conducted by Lennox Freemantle who is doing his MSC in Agricultural Economics. This research study is being conducted in his academic capacity and will not be made available to the public. The research project is titled, Whether the Decrease in Quantity in Wine grape Production will be counterbalanced by the Increase in Quality of Wine Grapes during Drought Periods in the Stellenbosch Region. You have been approached as a possible participant to explore how drought periods in your opinion affected the wine grapes quality and quality compared to normal periods. The data collected will be used to analysis whether the Decrease in Quantity in Wine grape Production can possibly counterbalance the Increase in Quality of Wine Grapes focusing on cabernet sauvignon grapes to see how water management can be used to optimize both quality and quantity Please take some time to read the information presented here, which will explain the details of this project and contact her if you require further explanation or clarification of any aspect of the study. Also, your participation is entirely voluntary and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point.

1. PURPOSE OF THE STUDY

Is to look at what impact droughts have on the quality and quantity of wine grapes especially cabernet sauvignon grapes since climate change has impacted the rain patterns. This study will allow grape growers and wine estates to see how grape quality and quantity is affected during drier years in the Stellenbosch region and show them what changes they can expect during drier years as

well as possible ways around these impacts to optimize both grape quality and quantity during drought periods

2. WHAT WILL BE ASKED OF ME?

If you agree to take part in this study, you will be asked a range of questions surrounding the quality and quantity of the grapes on the estate and your personal opinion on how droughts affect quality and quantity of grapes in general in addition to what factors indicated quality in wine grapes as well as possible methods to measure quality and finally. The questions will ask your opinion on what steps can be taken to ensure you optimize both quality and quantity during drier years.

3. POSSIBLE RISKS AND DISCOMFORTS

Foreseeable risks to this study are the possibility of reflecting on past harvests when either the quality or quantity of wine grapes was low or viticulture practices that have negatively influenced the quality or quantity of the wine grapes during a specific year as well as possible plans for future drought periods to optimize both the quality and quantity of the wine grapes.

4. POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY

The direct benefits of being part of this study are contributing to the academic field surrounding the impact of droughts on grape quality and quantity as well as providing information that could be used by future researchers and farmers to find ways to optimize both these factors during future drought periods

5. PAYMENT FOR PARTICIPATION

There will, unfortunately, be no payment as compensation to be part of this study.

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY, AND IDENTITY

Any information you share with me during this study and that could possibly identify you as a participant will be protected. This will be done by omitting any reference of specific individual's narratives and information shared. Data collected will be stored on a private password-protected device. The name of your estate/farm if applicable however will be included in the study and any specific iconic figures relevant to the estate/farm will be included in the study only with your

consent. Your estate/farm and any parties interviewed do have the option to opt-out of their information being shared if they wish. There is the possibility of the information collected for this study to be used for future publications and used for other academic or organizational purposes in the future such as Ph.D. or any organizational studies. All information collected through this questionnaire will be password protected on a device and will only be used for academic and educational purposes and will be erased after the study is completed and written. Any plans of publishing the results of the study will protect the identities of any specific parties involved whose reputation may feel threatened. Any information which the Estate/farm does not wish to share with the broader public outside the academic scope will remain confidential.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence. You may also refuse to answer any questions you don't want to answer and remain in the study. The researcher may withdraw you from this study if content collected unclear or does not provide a clear answer to each specific questions.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact Lennox Freemantle at 19006896@sun.ac.za and/or the supervisor Hein Gerwel at hgerwel@sun.ac.za

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights, or remedies because you participated in this research study. If you have questions regarding your rights as a research participant, contact Ms. Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.

- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I _____ agree to take part in this research study, as conducted by **Lennox Freemantle**.

_____ _____

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition, I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

_____ _____

Signature of Principal Investigator **Date**

Annexure D

The questionnaire used for the data collection

Analysis on Whether the Decrease in Quantity in Wine grape Production will be counterbalanced by the Increase in Quality of Wine Grapes during Drought Periods in the **Stellenbosch Region** focusing on Cabernet sauvignon

1. **How many hectares of red wine grapes are planted on the farm?**
2. **How many hectares of white wine grapes are planted on the farm?**
3. **What are the different cultivars grown on the farm**
4. **What is the average age of the Cabernet Sauvignon Vines?**
5. **With the decrease in rainfall over the last three years (2015 - 2018), has there been a decrease in total grape yield (roughly how much) If so, on a scale from 1-5, which cultivars have had the largest decline in yield and which cultivars have had the smallest decline in yield (for both red and white grape cultivars)?**
6. **How do you determine if the grapes produced in a certain season have higher or lower quality? * Is there a way to measure this grape quality**
7. **Does the grape quality or winemaker have a bigger influence on the quality of the wine produced in the end**
8. **Would you say the quality of the grapes on average has increased or decreased over the last three years (2015 till 2018)? On a scale from 1-5 (1 being the least 5 being the most), which cultivars have been decreased the most in terms of yield (for both red and white grape cultivars)? ***
9. **Will the quality of the red or white wine grape cultivars be affected more by the drought? Explain why and how. ***
10. **Has the drought improved the quality of the grapes**
11. **In your opinion will the Decrease in Quantity in Wine grape Production be counterbalanced by the Increase in Quality of Wine Grapes during Drought or has the drought-affected one of these factors more significantly?**

Scenario questions

1. **If the estate expects a drier year would you suggest adjust any viticulture practice such as Irrigation, fertilisation, mulching, cover crops or canopy management to try to optimise production in terms of quality and quantity?**
2. **If climate change continues and the average rainfall per annum decreases what soil types would suit vines in these drier conditions if any?**

3. **If climate change continues and the average rainfall decreases what cultivars would you replace and would you plant any other specific cultivars (both red and white) for the expected drier years to come?**

4. **What red cultivars are better suited to drought conditions compared to cabernet sauvignon**

More direct questions based on cabernet sauvignon

1. **Do the soil type and rootstock affect the cabernet sauvignon grape quality and quantity if so why**

2. **In your opinion why does Stellenbosch produce some of the best cabernet sauvignon in the country grapes? And why**

3. **How has the harvest dates of the cabernet sauvignon grapes been affected by the of 2015-2018 drought compared to prior years**

4. **Why was 2015 regarded as such a good vintage**

5. **In terms of quality, how do the following factors affect cabernet sauvignon? Is higher or lower better in your opinion better for quality grapes**

Berry weight (g)/size
Total soluble solids (Brix)
Juice PH
Titratable acidity
Total anthocyanins (mg/g)
Total phenolics (au/g)

6. **In your opinion how the following factors would be affected in a year with lower rainfall and does the farm collect such data.**

Berry weight (g)/size
Total soluble solids (Brix)
Juice PH
Titratable acidity
Total anthocyanins (mg/g)
Total phenolics (au/g)

7. **In your opinion does cabernet sauvignon grapevines produce better quality grapes during a drier year if so why**

8. **on a scale from 1-5 how did the drought of 2015-2018 affect the yield of cabernet sauvignon grapes(rough percentage) (1 being the least 5 being the most)**

9. **on a scale from 1-5 how did the drought of 2015-2018 affect the quality of cabernet sauvignon grapes (1 being the least 5 being the most)**

10. **In your opinion do you think the Decrease in Quantity of the cabernet sauvignon grapes has been counterbalanced by the Increase in Quality of Wine Grapes during (2015-2018) Drought or which one has been affected been impacted the most**

11. **In your opinion does quality or quantity play a bigger influence towards the price of the grapes**

12. **How the drought has influences the price of cabernet sauvignon grapes that the estate buys or sells.**